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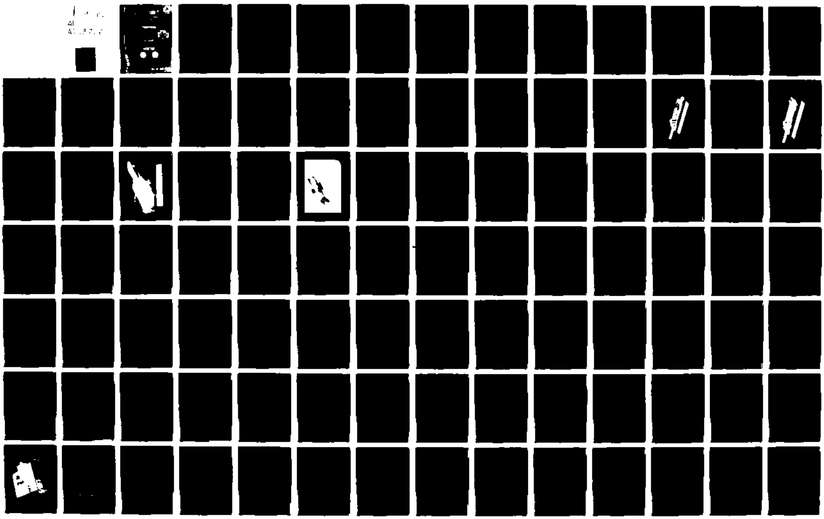

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

During the period 1 January - 31 December 1980, work under Contract N00014-76-C-0117 consisted of (1) final development of the ARL:UT profilometer recorder and transducer to enable the in situ measurement of compressional wave, shear wave, acoustic impedance, and static shear strength of ocean bottom sediments during geophysical coring, and (2) laboratory acoustical measurements on artificial sediments to test predictions of the Hovem model when the pore fluid viscosity is varied. The new profilometer recorder and

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transducer are described in detail as well as the microcomputer band playback system. Data obtained from the laboratory measurements are displayed.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION

Applied Research Laboratories, The University of Texas at Austin (ARL:UT), has for the past nine years been heavily involved in the field of low frequency acoustic propagation in the ocean. As part of the overall program of acoustic propagation studies, ARL:UT has had a program funded by ONR (Code 480) directed toward development of techniques and equipment to measure acoustic parameters of ocean sediments directly in situ. The initial goal of the program was to develop a method of measuring in situ compressional wave velocity and attenuation that would be both relatively cheap and easy, but one that would also produce accurate data. Methods available were (1) in situ measurements from platforms of various configurations, deployed either by cable from ships or by submersible, and (2) laboratory measurements on cores or other samples removed from the bottom. The first of these methods suffers from the fact that such measurements require additional ship time and specialized handling equipment and are slow and costly. The second method is, by comparison, easier and cheaper since cores are made on a routine basis, but the method can provide only inaccurate data since the process of sampling and retrieval causes physical disturbance to the samples as well as changes to the ambient temperature and pressure of the sample so that corrections based on assumed temperature and pressure in situ have to be made to the data.

With the above considerations in mind, ARL:UT developed a system to combine the best features of both methods. An instrument was developed to make acoustic measurements in situ in the bottom by attachment to a geophysical corer. The instrument requires only minor modification to the cutting edge of the corer and adds little in the way of cost or time to a normal coring operation.

Initially, only compressional wave velocity was measured by the apparatus, but as the program developed, other measurements were examined as additional features to be added to the measurement capabilities of the instrument. During the period covered by this report, the instrument was restructured to record six data channels to encompass a larger range of measurements. Included in the capability of the instrument are compressional wave velocity, shear wave velocity, acoustic impedance, static shear strength, and corer deceleration. Pulse amplitude data for both compressional and shear waves are also available. The deceleration is integrated by the system to provide a depth axis against which the other data are plotted. The deceleration data are also being examined to provide a measurement of the static shear strength of the cored sediment.[1] For this reason a transducer to independently measure static shear strength was included in the instrumentation.

This report discusses the new instrumentation and provides initial laboratory test data. The updated electronic circuits are provided in Appendices A and B, while the software required for the microprocessor playback unit is provided in Appendix C.

A program of laboratory measurement and computer modeling of acoustical propagation in sediments evolved from the in situ studies, due mostly to a requirement for these type data to enable the in situ data to be interpreted properly. It was realized early in the program that new transducers being developed for the in situ measurement tasks offered a unique opportunity to study acoustic processes in the laboratory. Analytical models based on the work of Biot[2] and Stoll[3] have been developed to augment the measurements and to develop an understanding of the fundamental processes in sediment acoustical propagation.

During 1980, the program was divided into two major parts.

1. Modification of the in situ measuring equipment to enable at least six data channels to be processed and recorded and final development of transducers for those measurements.

2. Laboratory measurements and model development to include artificial sediments with a variation in pore fluid viscosity.

A bibliography of publications under the sediment acoustics program is included as Appendix D. Since the program was started, 14 technical reports have been published, 13 papers have been presented at technical meetings, 7 papers have been published in scientific journals, 3 papers have been included in books, and 2 invention disclosures have been submitted for patent. Of these, 1 technical report and 1 invention disclosure were submitted during 1980.[4,5]

II. IN SITU MEASUREMENTS

A. Introduction

Field tests aboard R/V IDA GREEN in August 1979 showed that the shear wave transducer design being tested would operate and provide a shear wave velocity profile of ocean sediments.[4] The next step was to modify the in situ recording instrument so that more data channels could be accommodated to allow shear wave and compressional wave parameters to be recorded concurrently. Previous designs[6] were structured so that three data channels plus one reference channel were recorded on a 4-channel FM magnetic tape. The three data channels were (1) velocity (either compressional wave or shear wave), (2) amplitude (either compressional wave or shear wave as appropriate), and (3) acceleration. On playback, the output of the reference track was subtracted from the data track outputs to reduce noise associated with tape movement (wow and flutter) and to compensate for long term differences in the tape speed between record and playback. Approximately 10 sec of data were recorded on each tape. After noise compensation, the data were converted from analog to digital signals in the playback system and stored in digital memory. The acceleration data were then integrated by computer and the resultant depth data used as the x axis to plot velocity and amplitude as a function of depth on an x-y plotter.

To increase the number of data channels available in the system, it became necessary to multiplex two data channels on each of the recorder channels, which in turn required an increase in the bandwidth of the record-playback system. The increased bandwidth required faster tape speeds and increased power requirements for the tape drives which, coupled with the mechanical problems that had been encountered in the past with the tape drives, led to a decision to eliminate

the tape recording system altogether and instead go to a system to digitize the analog signals internally and store the digital data in a high density digital memory. The resulting design change has resulted in an instrument with increased bandwidth, lower power requirements, higher reliability, and increased data handling capacity. The new design will record six channels of analog data for 10 sec with a sample rate for each channel of 200 samples/sec. The total memory size is 12 kilobytes of digital data (2 kilobytes per channel) with a word size of 8 bits.

Concurrent with the redesign of the profilometer recording system, new transducers were designed to interface to the system to utilize the added capabilities. The new transducer arrangements include:

1. a set of compressional wave transducers to measure compressional wave velocity inside and outside the core cutter,
2. a set of transducers to measure compressional wave and shear wave velocity concurrently, and
3. a set of transducers to measure compressional wave velocity, acoustic impedance, and static shear strength.

The new design of the recording instrument is explained in Section B while a detailed explanation of the new transducer arrangements is presented in Section C. Laboratory tests were made of the new circuits and transducers and the results of these tests are presented in Section D.

B. Profilometer Development

The new profilometer recorder design is basically the same as the previous design.[1,6] The previous design for the mechanical layout of the system had allowed space for the addition of more printed circuit cards to allow shear wave measurements to be made in conjunction with the compressional wave measurements. The electronic circuitry is the same for both types of measurements with only changes in component values to allow for the differences in frequency and velocity between shear wave

and compressional wave measurements. The circuits have been described previously[1] and the description will not be repeated.

The point of departure between the old and new design is the recording of the analog voltages representative of the various measured parameters. Figure 1 shows a block diagram of the previous recorder design incorporating the magnetic tape unit. The dotted line separates the measurement part of the circuits from the recording part of the circuits. The circuit design has remained the same above the dotted line with the addition of identical circuits to measure the additional acoustical parameters. The FM modulators, reference frequency generator, and magnetic tape transport shown below the dotted line have been replaced by the new digital recording circuits.

Figure 2 shows a block diagram of the new profilometer recording system. The new additions to the circuitry include the measurement channels for shear wave velocity and amplitude, acoustic impedance, and shear strength, along with the analog-to-digital converter, the solid state memory, and control circuits for the digitizer and memory. General operations of each of the circuits will be described below, with a detailed circuit diagram and circuit description for only the new circuits included in Appendix A. The shear strength channel is shown connected to the digitizing circuit in Fig. 2 by a dotted line since it is not a permanent part of the measurement package, but will be implemented temporarily. When implemented, the shear strength measurement will replace the shear wave measurement since only six data channels are available in the recorder. Changes to the data channels are made by simple wiring changes on the connectors inside the instrument and require only a few minutes to alter the measurement capability of the instrument.

The compressional wave measuring circuits are identical to those reported previously[1] for the existing profilometer design with the exception that the timing of the pulse generator is synchronized to the digital recorder. As in the previous design, the pulse generator

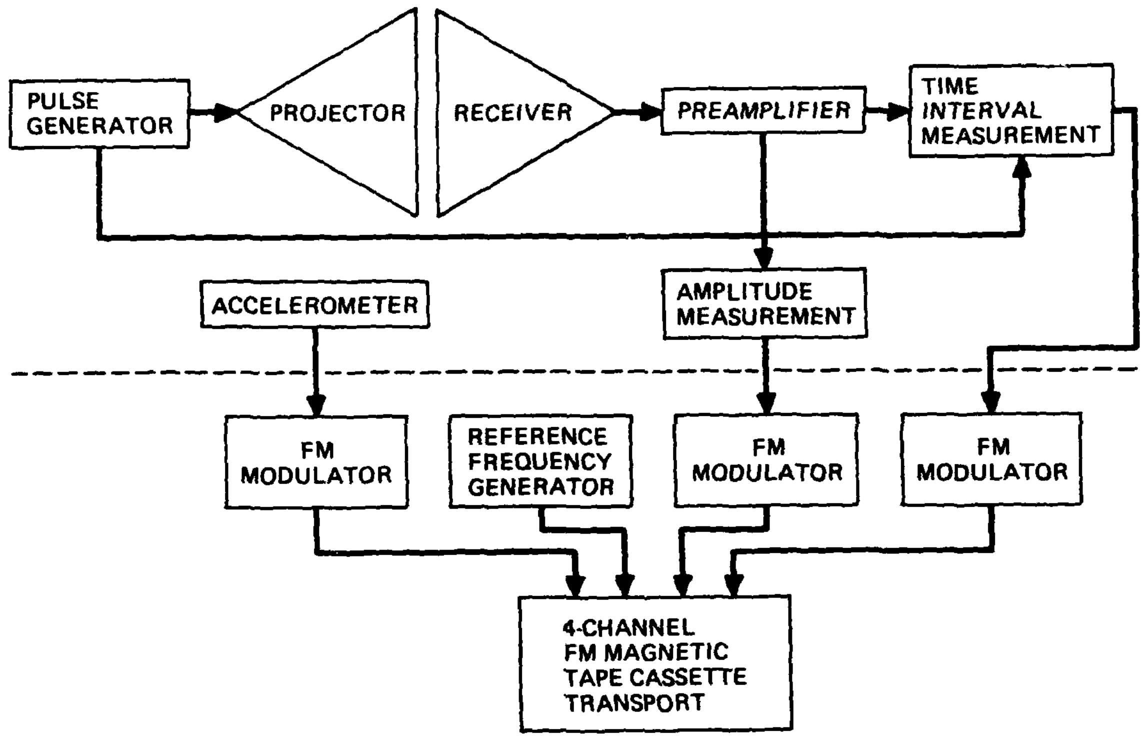

FIGURE 1
BLOCK DIAGRAM OF THE PROFILOMETER RECORDING UNIT
WITH MAGNETIC TAPE RECORDER DATA STORAGE

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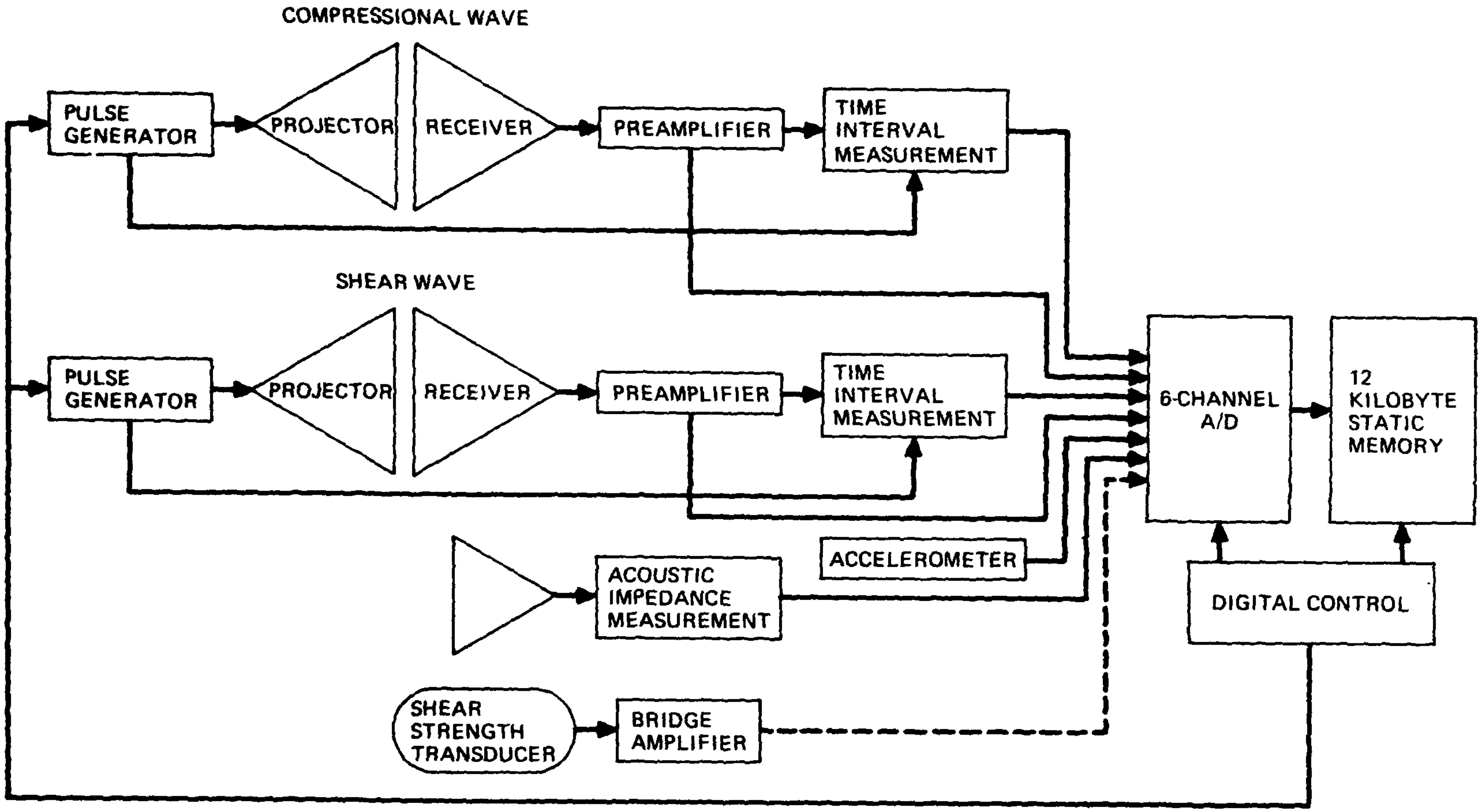

FIGURE 2
BLOCK DIAGRAM OF THE PROFILOMETER RECORDING UNIT WITH SOLID STATE DIGITAL DATA STORAGE

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provides a series of 2.5 μsec pulses to the compressional wave projecting element mounted in the cutter of the corer. The pulses are at an amplitude of 10 V and a repetition rate of 200 pulses per second. A pulse of compressional wave acoustic energy is emitted by the projector and travels through the sediment across the inside diameter of the corer. A receiving element detects the acoustic pulse and generates an electrical pulse which is amplified and filtered by the preamplifier circuit. The amplitude of the pulse is also detected and an analog voltage proportional to the pulse amplitude is provided to one channel of the digitizer. The amplified and filtered pulse is then converted to a train of square pulses by a zero crossing detector and the time interval between the time a pulse is emitted by the pulse generator and the time of arrival of the first pulse in the received pulse train is converted to an analog voltage and provided to another channel of the digitizer.

The shear wave channel is identical to the compressional wave channel with the exception that component values in the circuits are selected to accommodate a lower frequency and a slower velocity for the shear wave. In fact, the shear wave channel can be used for a second channel of compressional wave measurement by the use of appropriate circuit cards in the shear wave positions. Table I shows the required characteristics for the two types of measurements.

Due to the possibility that electrical feedover in the cables from the electronic circuits to the transducer could cause interference between the two measurement channels, synchronization by the digital control circuit is such that the generation of the shear wave pulse is delayed 1.5 msec after the compressional wave pulse to allow the compressional wave measurements to be completed before the shear wave measurement is initiated. The shear wave measurement is then completed before another compressional wave measurement is again started.

The accelerometer measures the deceleration of the corer. The circuit has not been changed and is identical to that used in the previous design.[1] The accelerometer consists of a cantilever mounted

TABLE I

PARAMETERS FOR THE COMPRESSIONAL WAVE AND SHEAR WAVE MEASUREMENT CHANNELS

	Compressional Wave	Shear Wave
Frequency	200 kHz	2 kHz
Velocity Range	1400-1900 m/sec	25-300 m/sec
Filter Bandwidth (3 dB)	150-250 kHz	1-10 kHz
Generator Pulse Length	2.5 μsec	250 μsec
Repetition Rate	200 pps	200 pps

ceramic bender element with a small mass mounted on the free end. A charge amplifier circuit amplifies the signals resulting from changes in acceleration and provides them to one channel of the digitizer.

The acoustic impedance measurement is similar to that described for laboratory measurements.[7] The acoustic impedance circuit provides a cw signal to the transducer element mounted on the core cutter. Frequency of the signal is 400 kHz and is maintained at a constant 5 Vpp level. The electrical current amplitude is detected by a resistor in series with the acoustical element and is rectified to provide an analog voltage that is proportional to the electrical impedance of the acoustical element. The electrical impedance of the element is proportional to the acoustic impedance of the sediment in contact with the element. For simplicity in the electronic circuits, no attempt is made to maintain the driving frequency at the resonance frequency of the element; the resonance frequency changes as the acoustic impedance changes and results in phase differences between the voltage and current waveforms. Instead, the frequency is set at resonance with the element in water and is maintained constant. The result is that the analog output is not a linear function of acoustic impedance. However, calibration can be done so that the output as a function of acoustic impedance is known.

The static shear strength measuring transducer consists of a small penetrometer body attached to one of the acoustic transducer housings. A strain gauge is attached to the penetrometer and connected to the electronic circuits of the instrument. Changes in strain gauge resistance in response to varying load on the penetrometer body are detected and amplified by a bridge amplifier and provided to one channel of the solid state recorder.

The solid state recorder consists of a 6-channel multiplexer, a sample-and-hold amplifier, an analog-to-digital converter, a 98,304 bit static memory organized as 12,288 x 8-bit bytes, and a digital control circuit to initiate recording, to synchronize pulse generation of the measuring circuits and the multiplexing of data channels, and to supply

appropriate addresses and chip select signals to the static memory. Detailed descriptions of the circuits are provided in Appendix A. Each data channel thus occupies 2 kilobytes in the memory and at a repetition rate of 200 pps will provide 10 sec of recording time. The recording of data is initiated by the tripping of a switch when the corer is triggered at the ocean bottom and starts to free-fall. Free-fall and penetration of the corer usually occur in 3 to 8 sec, depending on the length of core barrel and stiffness of the bottom sediments.

Once data have been recorded and the instrument recovered aboard ship, it is necessary to process the data and reduce it to a usable form. Figure 3 shows a block diagram of the playback system used with the previous profilometer design. The system consists of a tape transport and demodulator unit to convert the FM data recorded on tape to analog voltages. The unit has three data outputs which are provided to the microcomputer unit in which the three data channels are digitized and the accelerometer data integrated twice to provide depth data. The microcomputer output is input to an x-y plotter where the three data channels are plotted as a function of depth.

The new design eliminates the tape transport and demodulator unit and instead an interface cable from the microcomputer plugs directly into the sockets in the recorder unit normally occupied by the digitizer and digital control cards. The microcomputer addresses the recorder's static memory and transfers all the data from recorder memory to memory located internal to the microcomputer. Once inside the microcomputer, the data are manipulated and plotted in the same manner as before.

C. Transducer Development

In order to utilize the increased recording capacity of the new profilometer recording instrument, three sets of transducers have been developed and constructed. Each of the three transducer designs was developed to address a particular problem in the area of in situ

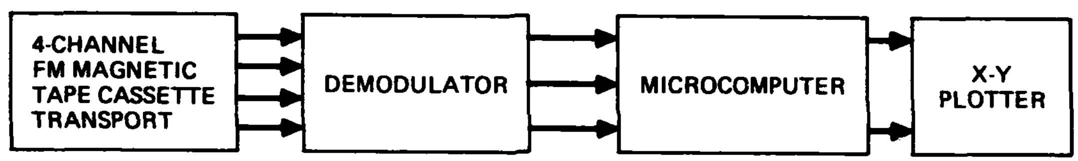

FIGURE 3
BLOCK DIAGRAM OF THE PROFILOMETER
PLAYBACK SYSTEM USING MAGNETIC TAPE

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4 - 16 - 81

acoustical measurement. One problem was to measure the amount of disturbance to the sediment that occurs before the in situ measurement is made. The profilometer transducers are mounted such that the transducer elements are about 5 cm back from the cutting edge of the core cutter to maintain the strength and structural integrity of the cutter assembly.[6] Even this short distance could introduce a measurable amount of disturbance to the sediment and affect the acoustical measurement. A solution to the question of disturbance is to place another set of transducer elements in a position out in front of the cutting edge so that a comparison can be made between the two positions. The front transducer, of course, will also disturb the sediment to some degree, but a measurement of the difference can be made and an estimate of the amount of disturbance developed from the data. A bonus to the above measurement is that the travel paths for the two transducer sets can be made different so that a measurement of attenuation can be obtained. The reason that attenuation measurements cannot be obtained from the pulse amplitude data that are presently recorded by the profilometer equipment is that the amplitude is dependent not only on attenuation of compressional waves in the sediment, but also on the variation of the coupling between the transducer element and the sediment. With two sets of identical transducer elements operating over two different path lengths, the changes to signal amplitude due to variation in coupling can be eliminated so that the attenuation can be calculated.

The second problem to be addressed by transducer design was the concurrent measurement of shear wave and compressional wave parameters that has been the ultimate goal of the in situ measurement program for the past several years. A successful shear wave transducer design was demonstrated in FY 79 and the composite shear wave/compressional wave transducer is based on that previous design.

A third transducer design addresses the problem of an acoustic impedance transducer capable of operating at high ambient pressures. Such a design has been proposed and tested in the laboratory[1] and the

third transducer set incorporates this design along with a set of compressional wave elements operating to measure compressional wave velocity in the usual way.

This same transducer set also addresses another problem, which is the measurement of shear strength of a sediment in situ. Preliminary work on adapting the accelerometer data from the profilometer to calculate shear strength has been done,[1] but there are so many unknown factors associated with the calculations that it was desired to have an independent measurement of shear strength for comparison. For this reason a penetrometer measurement was added to the third transducer set.

Figures 4, 6, and 8 show schematic cross-sections of the three transducer designs as they would be mounted on a cutter and illustrate the relative positions that the acoustical elements occupy. In all three designs, a pair of compressional wave elements occupy the same relative position as in the previous profilometer compressional wave transducer design, and thus the new transducer design can be used on the same modified cutters as previously without further modification.

From Fig. 4, the difference in separation between the set of elements inside the cutter and those outside the cutter is 2.3 cm. Since the expected attenuation range for compressional waves at 200 kHz in ocean sediment is from 10 to 100 dB/m,[8] the above difference in separation should yield a difference in recorded signal levels of from 0.23 to 2.3 dB between the two channels. Such a difference should be easily observable on the output from the instruments. Thus a directly measured attenuation profile of ocean bottom sediment would be obtained for the first time in situ. A photograph of the dual compressional wave transducer is shown in Fig. 5.

Figure 6 shows the relative positions of the shear wave and compressional wave transducer elements on the composite transducer set. Again the shear wave elements are positioned outside and ahead of the

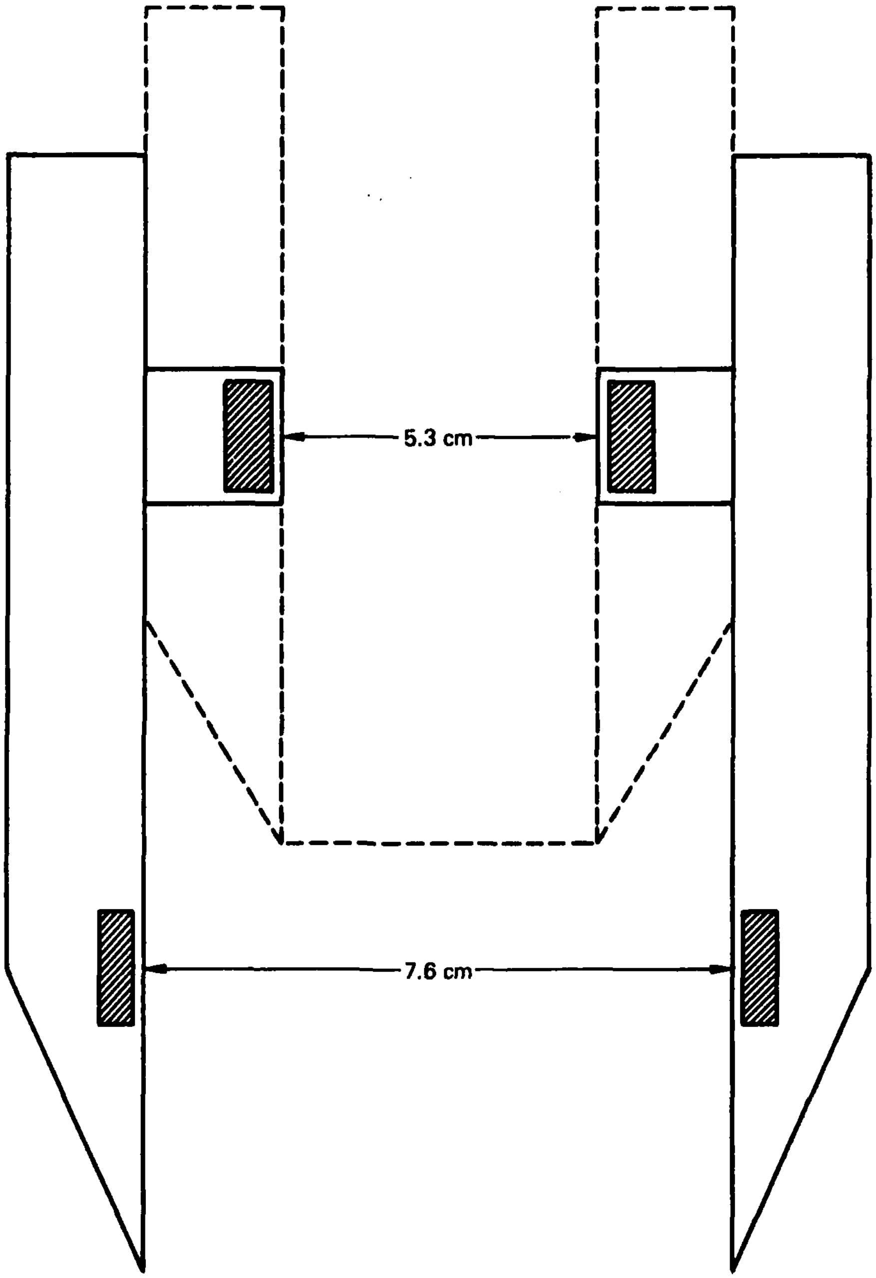

FIGURE 4
SCHEMATIC DRAWING OF THE PROFILOMETER DUAL COMPRESSIONAL WAVE TRANSDUCER SET SHOWING RELATIVE POSITIONS OF TRANSDUCER ELEMENTS

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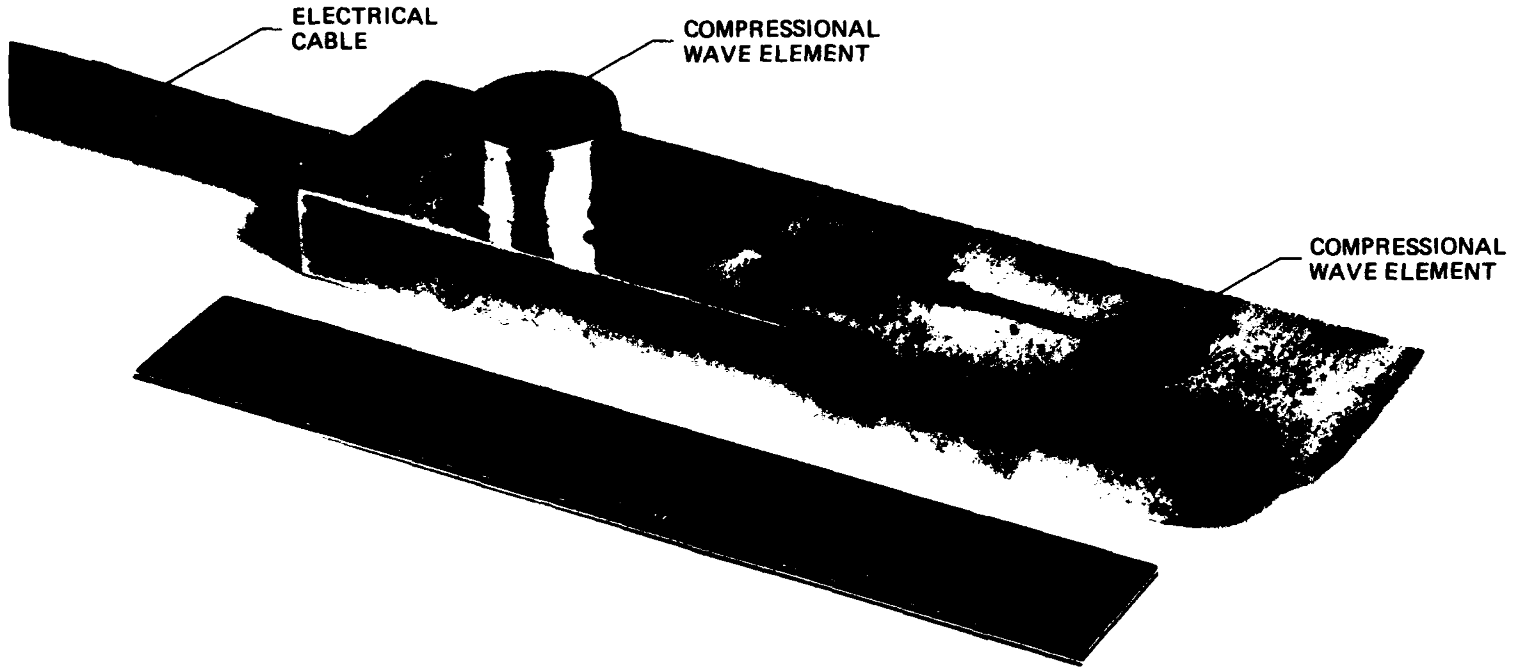

FIGURE 5
TWO-CHANNEL COMPRESSIONAL WAVE PROFILOMETER TRANSDUCER

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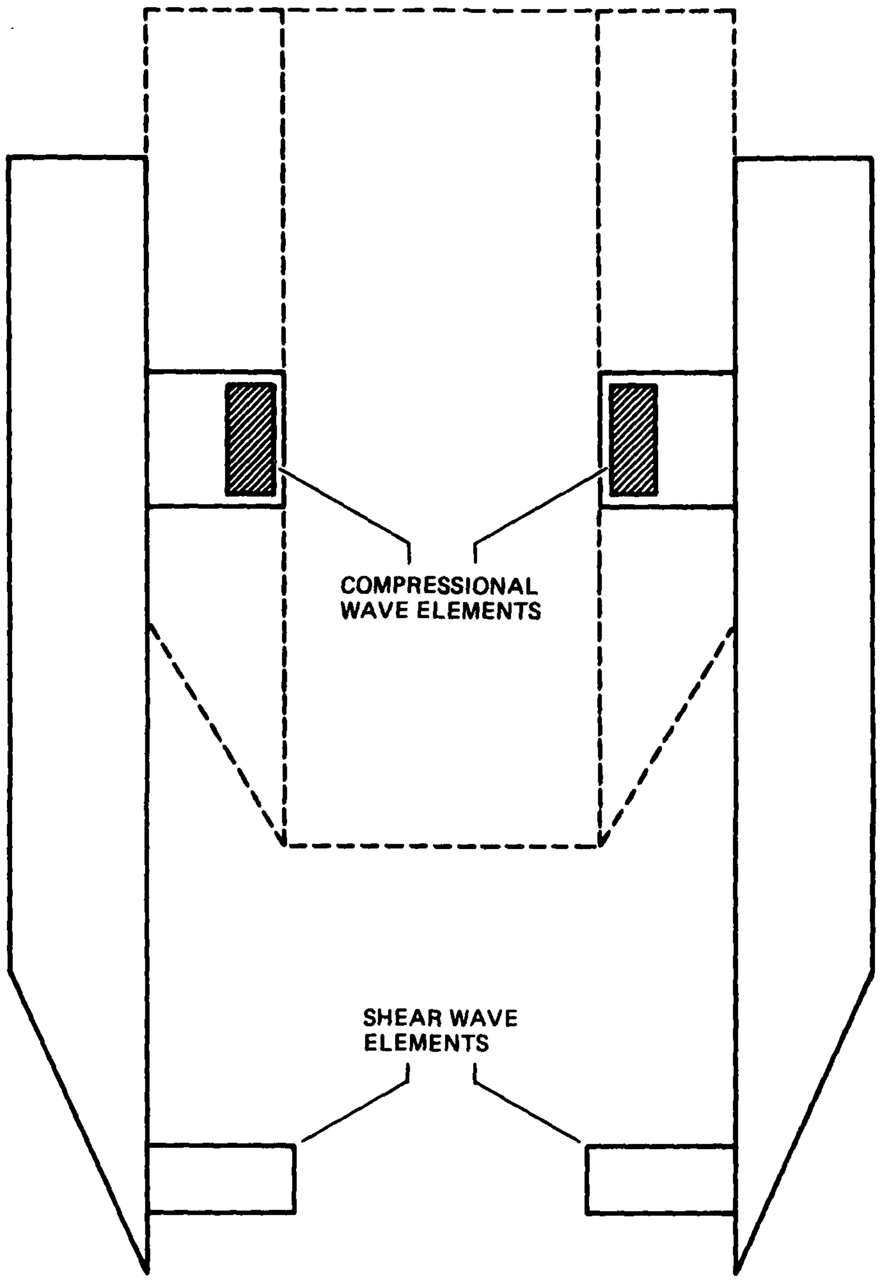

FIGURE 6
SCHEMATIC DRAWING OF THE PROFILOMETER COMPRESSIONAL WAVE/SHEAR WAVE TRANSDUCER SET SHOWING RELATIVE POSITIONS OF TRANSDUCER ELEMENTS

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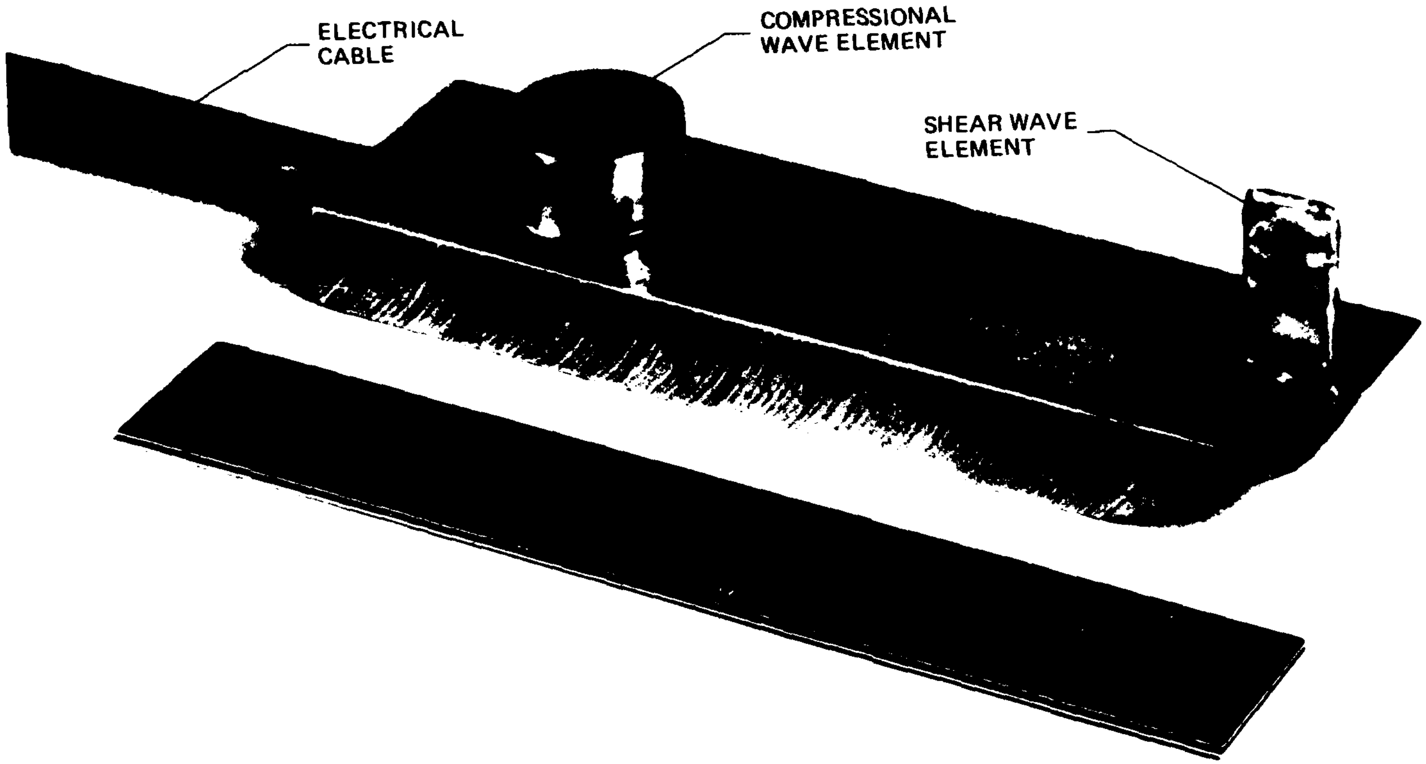

FIGURE 7
SHEAR WAVE/COMPRESSIONAL WAVE PROFILOMETER TRANSDUCER

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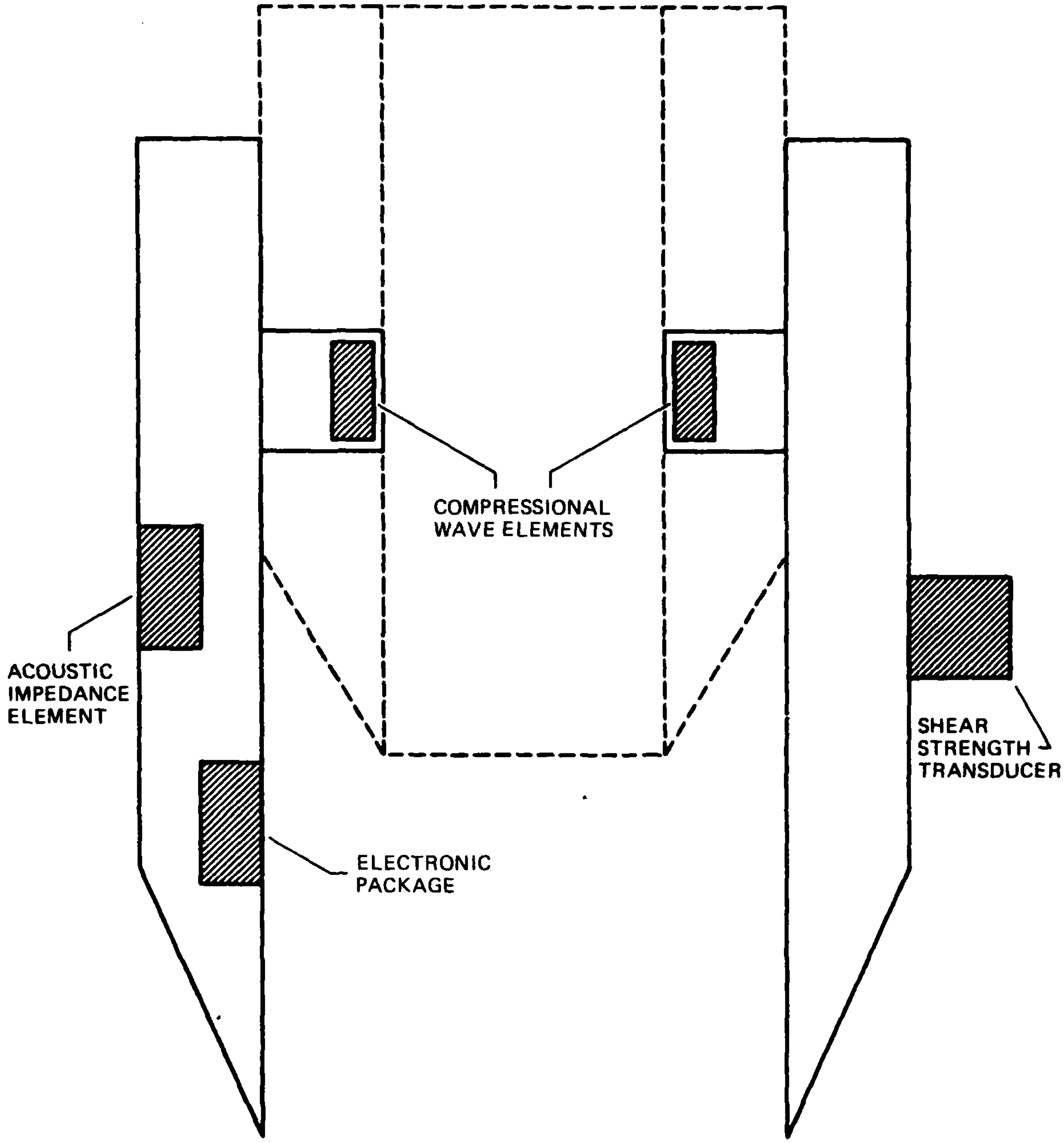

FIGURE 8
SCHEMATIC DRAWING OF THE PROFILOMETER TRANSDUCER SET TO MEASURE COMPRESSIONAL WAVE SPEED, ACOUSTIC IMPEDANCE, AND SHEAR STRENGTH

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DJS - GA
4 - 16 - 81

cutter to allow the whole shear wave element to be in contact with the sediment to increase shear wave coupling to the sediment. The design is identical to that used to successfully obtain a shear wave profile in the Gulf of Mexico in FY 79.[4] The forward position of the shear wave element increases the hazard from hard layers, so the new design was made more rugged by constructing the bender element from a layer of piezoelectric ceramic and a layer of stainless steel. The resulting shear wave transducer is more rigid and less sensitive than one made from two ceramic layers, but tests indicate that sensitivity is still sufficient to enable operation in most natural sediments. Figure 7 shows a photograph of the transducer set.

The third transducer set is illustrated in Fig. 8. In the previous two transducer sets that have been described, both projector and receiver transducers were identical. For the third set it was necessary to put the active transducers (the compressional wave projector and the acoustic impedance transducer) in one housing and the passive transducers (compressional wave receiver and shear strength transducer) in the other to eliminate interference. A small electronic package is also included in the housing with the acoustic impedance transducer to provide necessary decoupling circuits between the cable capacitance and the transducer element. The two transducers are thus different in construction and are not interchangeable.

Figure 9 shows a photograph of the transducer which incorporates the acoustic impedance element. The design of the element is the same as that first tested in FY 78.[1] A cross sectional drawing of the transducer design is shown in Fig. 10 and illustrates the various components of the device. The radiating head for the present device is made of hardened tool steel and was tested to a pressure of 3.45×10^7 N/m^2 (5000 psi) before the disc ruptured. Such a pressure represents about 3.5 km of water depth. The ceramic element is a 1.59 cm diam disc 1.43 mm thick and is attached to the steel radiating head by rigid epoxy cement. The transducer element is held in place in the housing by a threaded ring and is sealed by an O-ring. A small electronic

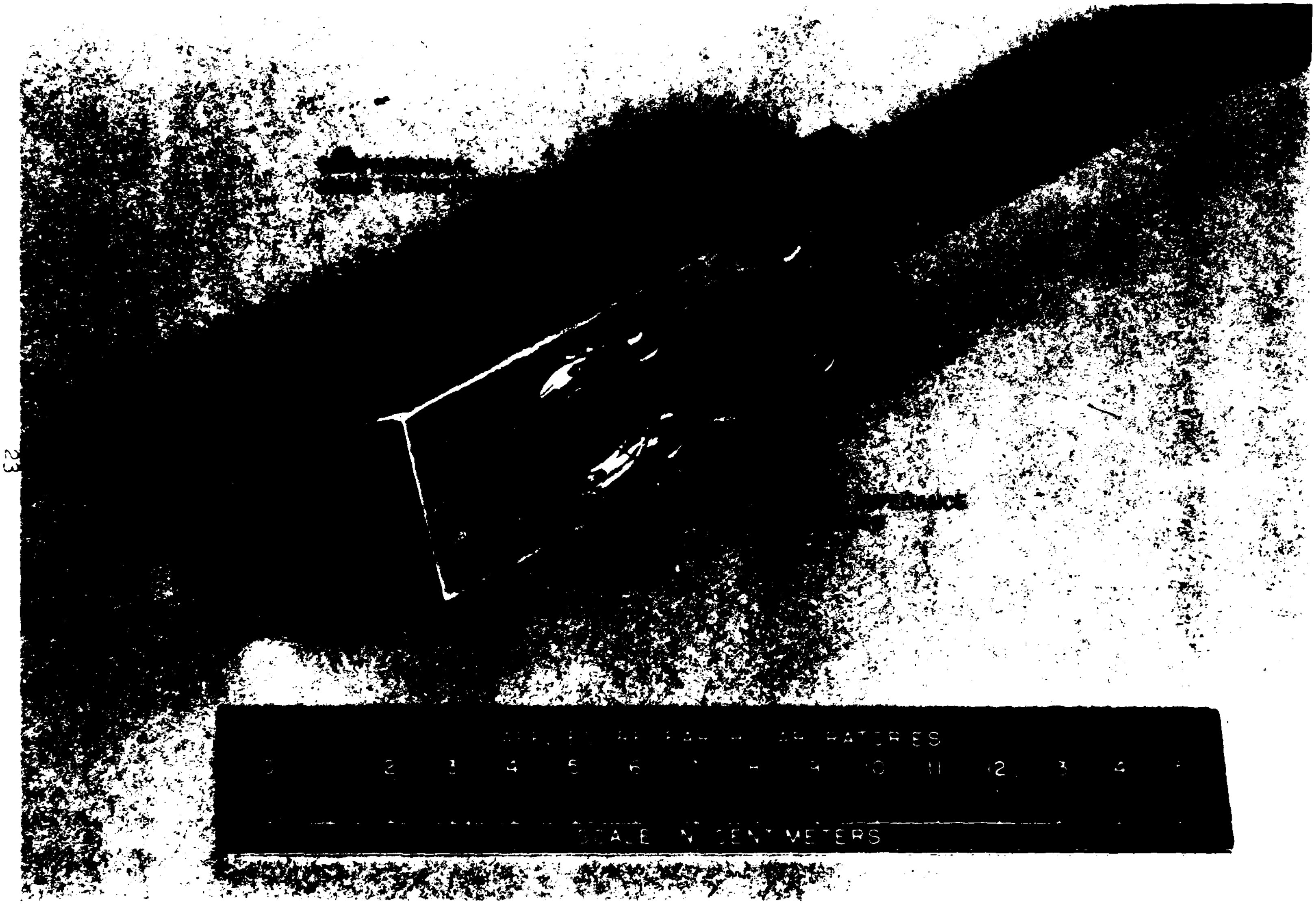

FIGURE 9
COMPRESSIONAL WAVE/ACOUSTIC IMPEDANCE PROFILOMETER TRANSDUCER

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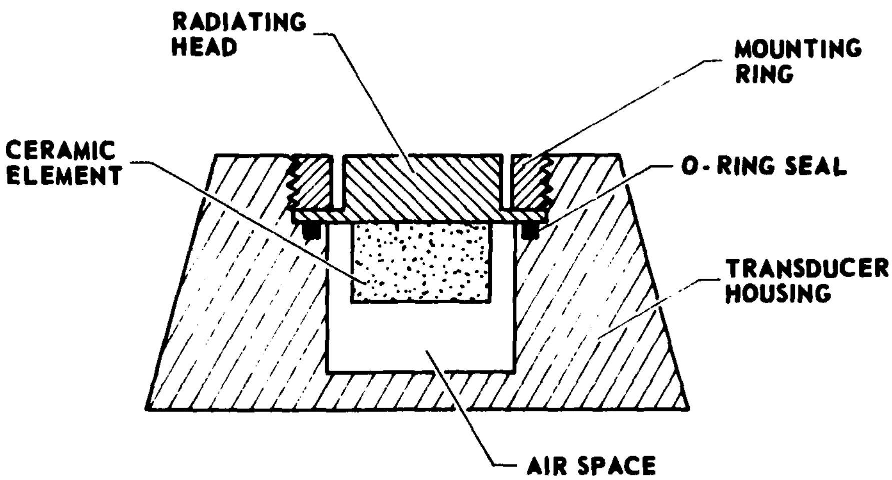

FIGURE 10
CROSS SECTION OF ACOUSTIC IMPEDANCE TRANSDUCER

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circuit is also incorporated in the tranducer housing and consists of a two-channel operational amplifier integrated circuit. One channel of the amplifier drives the element to isolate it from the capacitance of the interconnecting cable; the other channel rectifies the signal obtained from a current detecting resistor to keep the capacitatively coupled ac driving signal in the cable from interfering with the detected signal. Detailed descriptions of the electronic circuits can be found in Appendix A.

Figure 11 is analogous to Fig. 9 and shows the unit containing the compressional wave receiver and the transducer used to measure shear strength. The shear strength transducer consists of a small penetrometer body 1 cm x 1 cm x 2.5 cm long. The leading edge is sharpened and tapered in an ogive shape and is attached to a 1 cm long cantilever beam welded to the transducer housing. The beam has a pair of metal strain gauges attached to the top and bottom and connected as two arms of a balanced bridge. The beam is encased in epoxy plastic shaped to match the shape of the penetrometer. The force experienced by the penetrometer during penetration of a sediment causes the beam to deflect slightly upward, which reduces the resistance of the upper strain gauge and increases the resistance of the lower. Any change in resistance due to temperature tends to cancel since both strain gauges are identical and in opposite arms of the bridge.

D. Laboratory Tests

The three sets of transducers were tested in a laboratory tank for proper operation. The tank was 0.6 m diam by 2 m deep and had approximately 1 m of sediment and 1 m of overlying water. The sediment consisted of a water saturated ball clay (pottery clay), which has been used for previous transducer tests. The transducers were mounted on a core cutter which was mounted on a 3 m length of aluminum pipe; the transducers were attached to the profilometer recorder by electrical cables. The analog outputs of each of the measurement circuits were

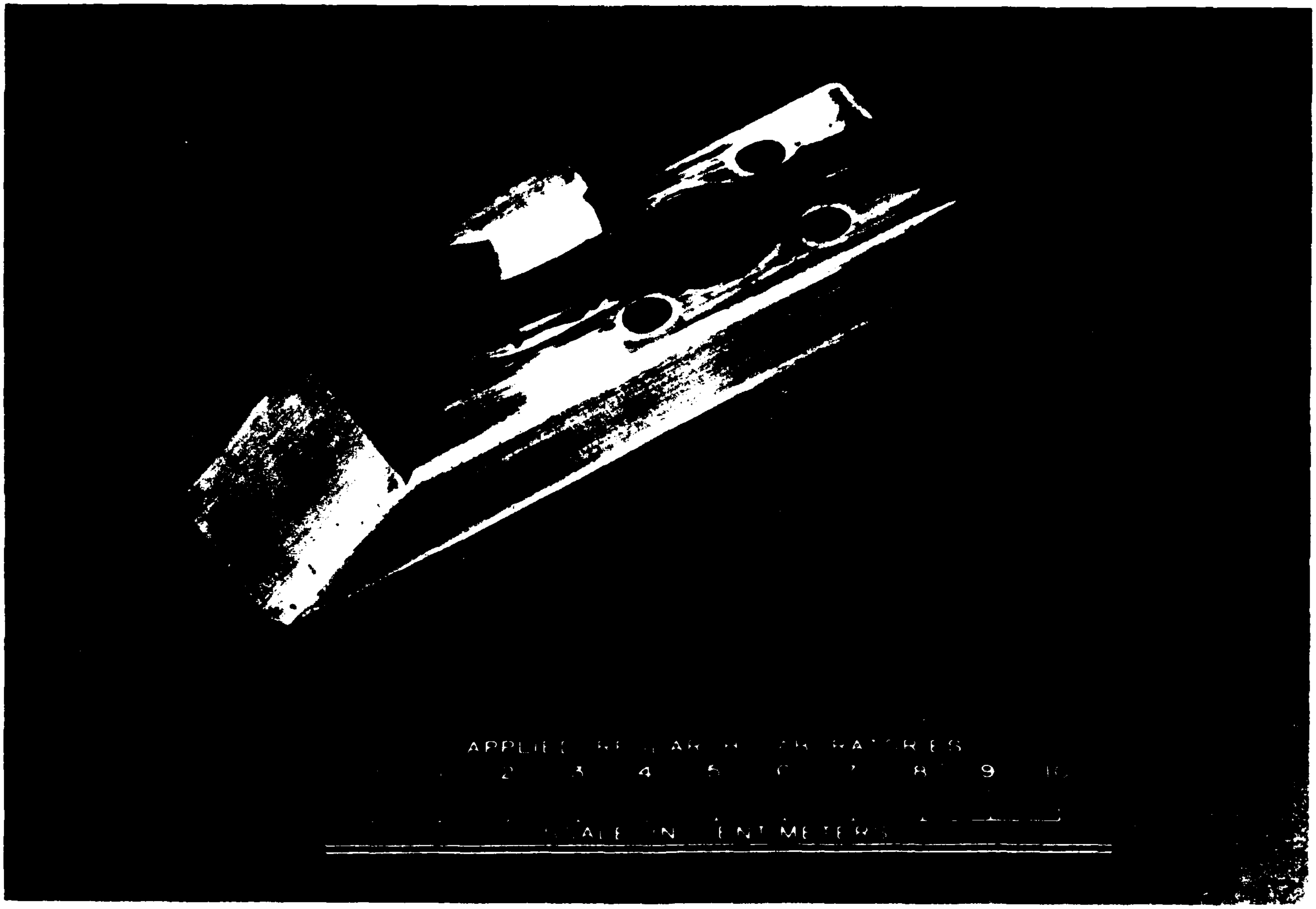

FIGURE 11
COMPRESSIONAL WAVE/SHEAR STRENGTH PROFILOMETER TRANSDUCER

recorded directly on a strip chart recorder since the solid state recording circuits had not been completed at the time of the tests. To test the transducers dynamically, the cutter and pipe were pushed into the sediment by hand while the electrical signals were recorded. An attempt was made to maintain a constant speed of insertion so that the time axis of the strip chart recorder would represent as closely as possible the penetration depth for the test. Figure 12 shows the results of the test using the dual compressional wave transducer set. Because the strip chart recorder had only two channels, only the velocity outputs were recorded. Since the clay had a high porosity, the compressional wave velocity is slightly lower in the sediment than in the overlying water and shows a gradient toward the bottom where the clay tended to increase in stiffness. Apart from a few noise spikes, the profiles are smooth and seem to be identical. There is an offset in the depth axis between the two profiles due to the separation of the transducer element pairs.

Figure 13 shows the results of laboratory tests for the shear wave/compressional wave transducer set. The top trace is the compressional wave velocity and is similar to those shown in Fig. 12, except the profile is less smooth due to disturbance to the sediment during the first test. The lower trace is the shear wave velocity. In general, the shear wave velocity follows fairly closely that of the compressional waves, with a lower velocity at the top of the sediment gradually increasing toward the bottom, with some variations probably due to the sediment having been disturbed by previous tests. While the shear wave elements are in the overlying water at the beginning of the profile, the trace is offscale due to detection of the feedaround signal in the cutter providing a signal to the instrument that appears to be a very fast shear wave (about 400 m/sec). As soon as the shear wave elements contact the sediment, the feedaround signal is damped out and the actual shear wave is measured. The large noise spikes at the end of the shear wave profile are probably due to the cutter striking the bottom of the test tank.

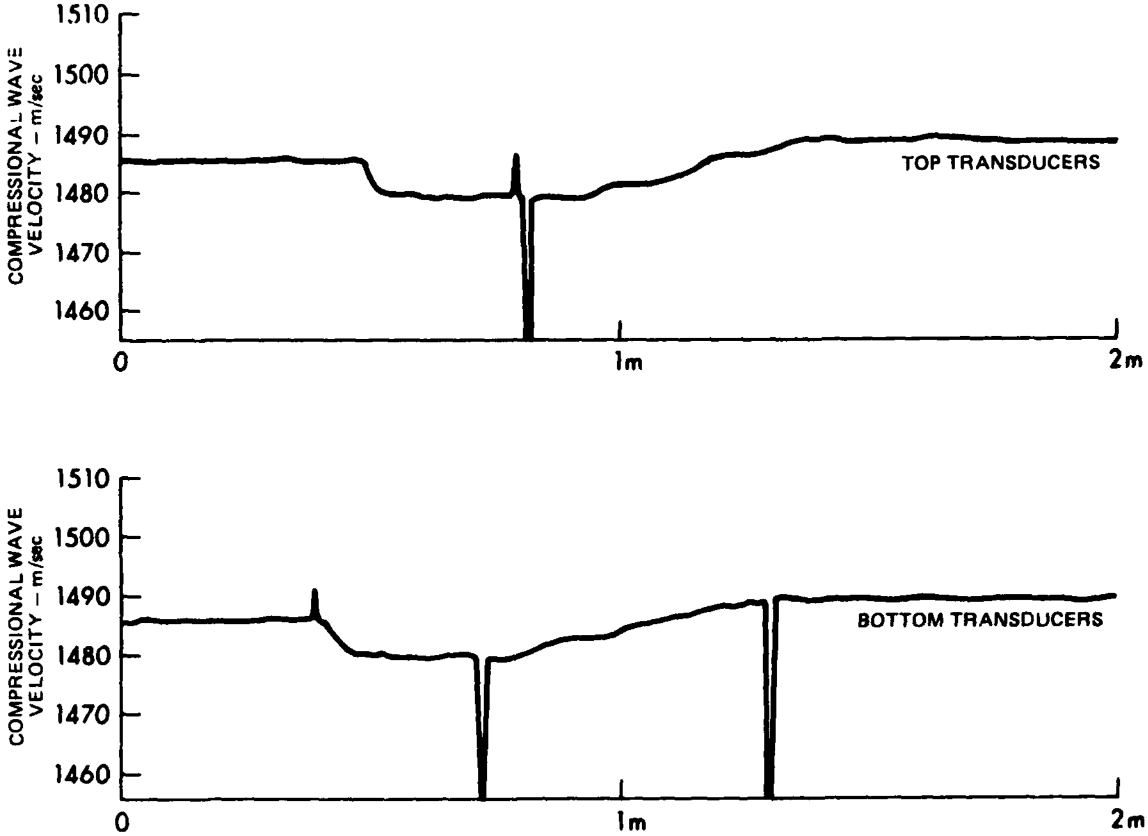

FIGURE 12
COMPRESSIONAL WAVE VELOCITY PROFILES IN A SEDIMENT TEST TANK

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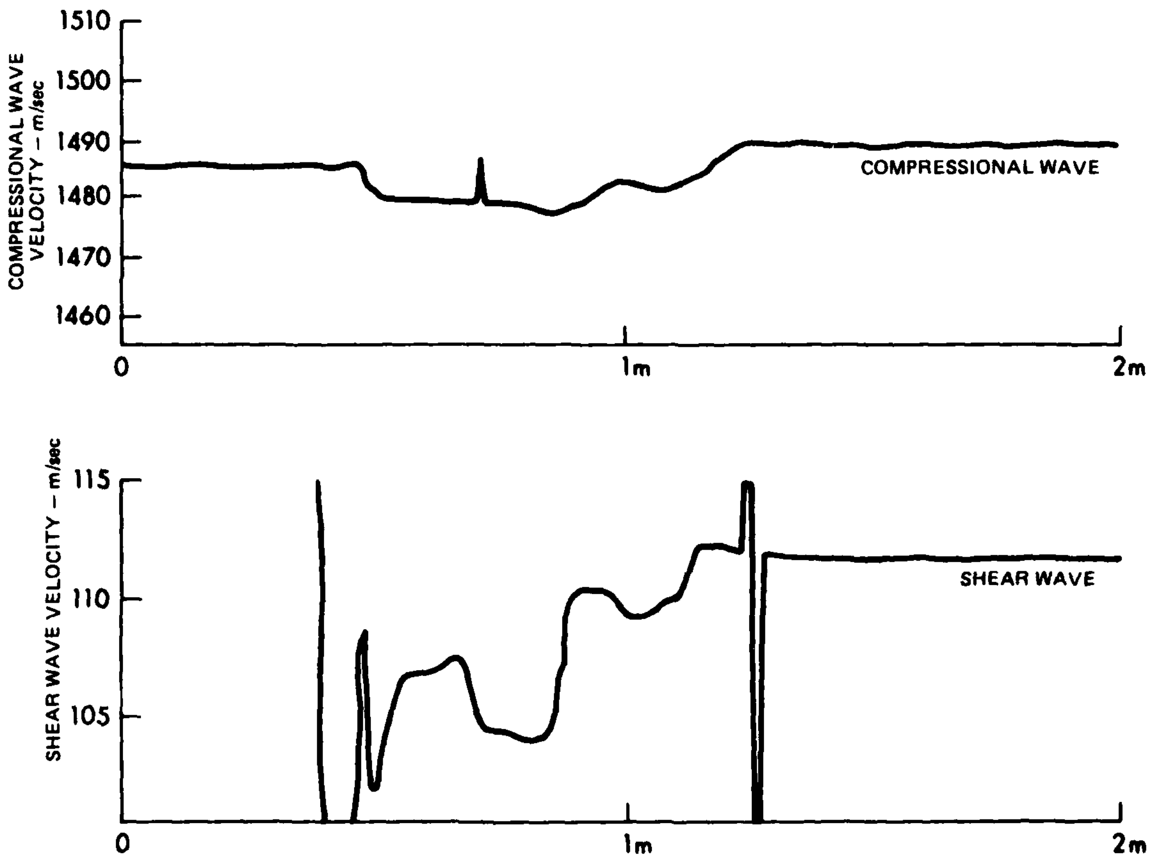

FIGURE 13
COMPRESSIONAL AND SHEAR WAVE VELOCITY PROFILES
IN A SEDIMENT TEST TANK

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Figures 14 and 15 show the results of laboratory tests of the third transducer set, which was designed to measure compressional wave velocity, acoustic impedance, and static shear strength. The restriction of two channels on the strip chart recorder required that the acoustic impedance and shear strength measurements be tested separately. Figure 14 shows concurrently made profiles of compressional wave velocity and acoustic impedance. Increased disturbance to the sediment from the series of tests tended to homogenize the sediment so there was little variation of either parameter from top to bottom. Figure 15 also shows little variation, but enough to show that the transducers operated satisfactorily. The variation in acoustic impedance measured during the test was 2.2×10^3 acoustic ohms (1 acoustic ohm = 1 g/cm^{2}ga) and was smaller than expected, but the sediment was pretty well disturbed by that time even though the tests occurred over a period of three days. The sediment had previously been undisturbed for over a year.

The results of the laboratory tests on the three transducer sets were judged to be satisfactory. The next step, then, is a sea test to evaluate their operation in an environment where stresses on the components are much larger and more uncontrollable.

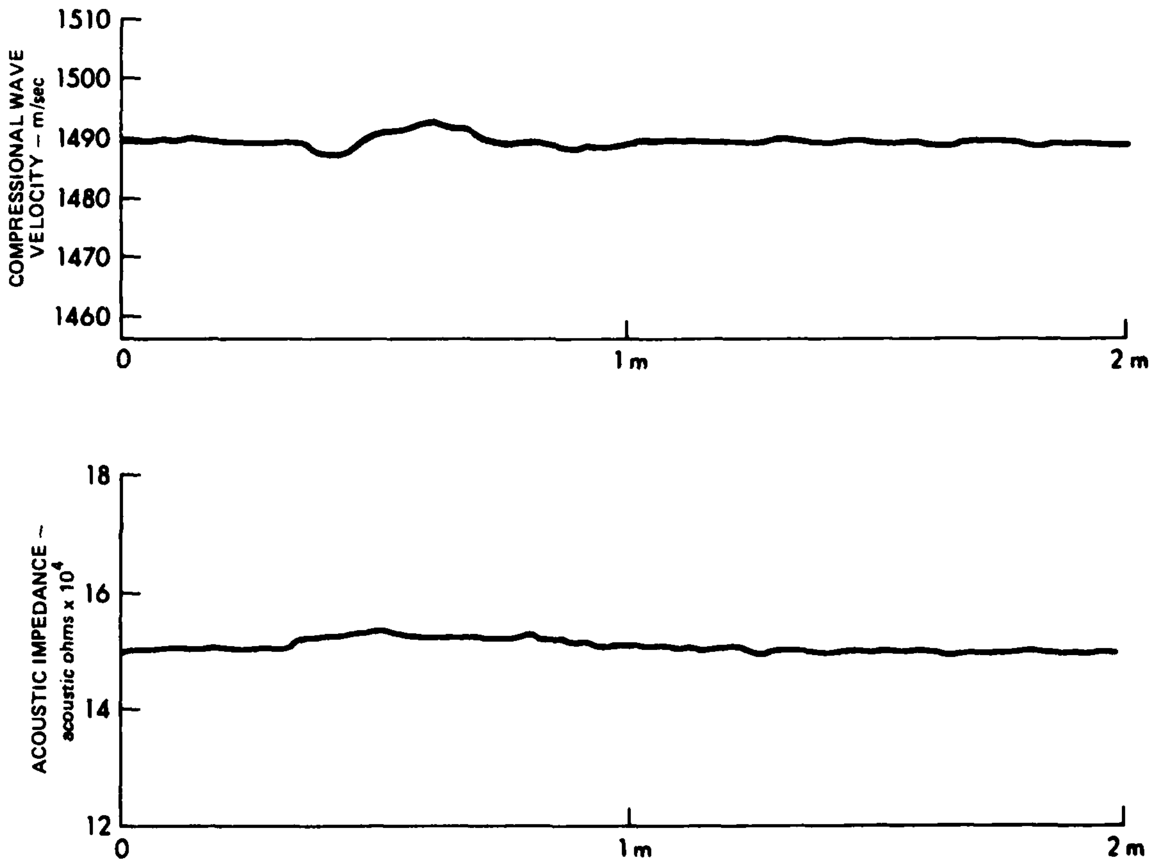

FIGURE 14
COMPRESSIONAL WAVE VELOCITY AND ACOUSTIC IMPEDANCE PROFILES IN A SEDIMENT TEST TANK

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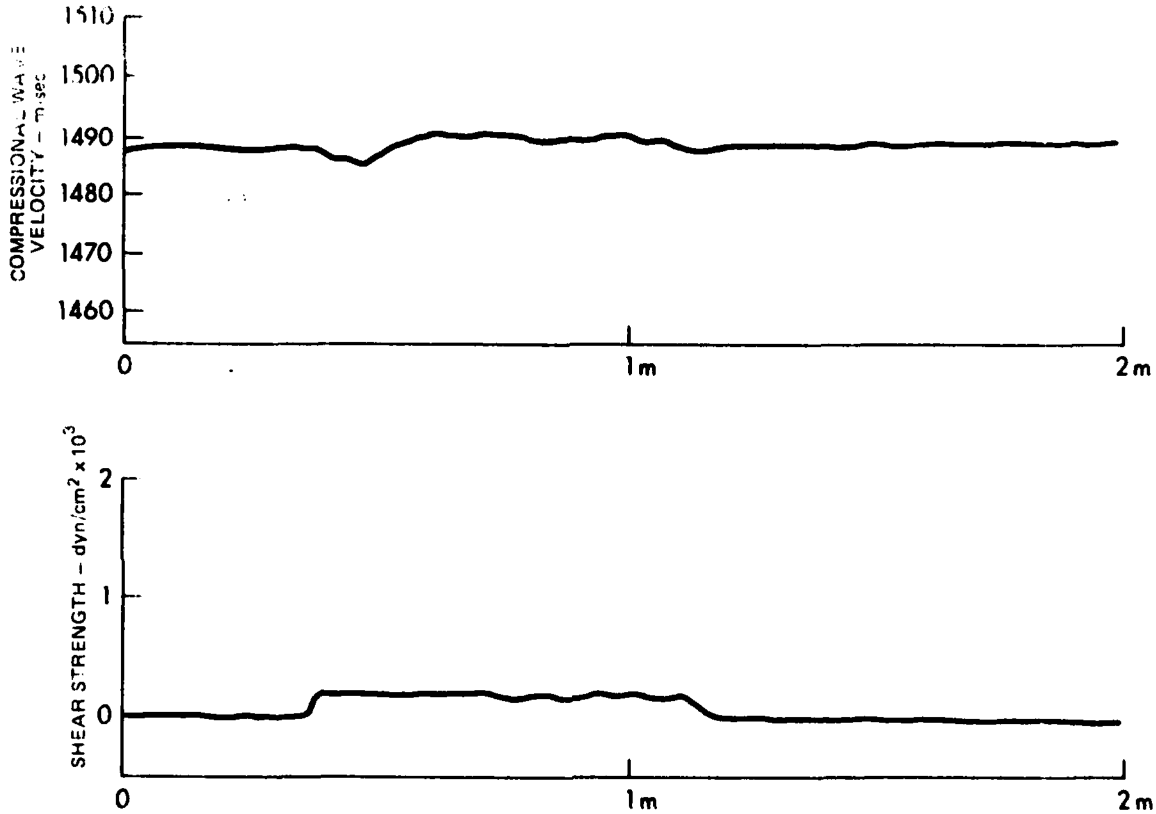

FIGURE 15
COMPRESSIONAL WAVE VELOCITY AND SHEAR STRENGTH PROFILES IN A SEDIMENT TEST TANK

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III. LABORATORY MEASUREMENTS

A. Introduction

An important part of the sediment acoustics program at ARL:UT has been the development of analytical models for the propagation of acoustical energy through sediments and the testing of these models and resulting predictions by acoustical measurements in the laboratory on natural and artificial sediments.

During FY 78 and FY 79, Bell[8] and Hovem[9] developed models of acoustical propagation in sediments based on the work of Biot[2] and Stoll.[3] The Biot and Stoll models were intended to be used for propagation in natural sediment types with a wide range of parameter variation. As a consequence, several of the parameters to be inserted in those models have to be assumed from measurements in real sediments. The efforts of Bell and Hovem were directed at developing a specialized model with simple geometry and little variation in parameters. Such a model would have little utility for application to a real sediment, but if the parameters of the model are selected so that they can be easily duplicated in a controlled laboratory environment then predictions and behavior of the specialized model can be more easily understood and evaluated than those of the general model.

During FY 80, the specialized model was used to investigate the acoustical behavior of a sand-type sediment with a single size of spherical grains and a pore fluid of variable viscosity. The work is described in the next section.

B. Background

Hovem and Ingram[9] previously set up a model based on the Biot theory to examine the frequency response of compressional waves in a spherical grain sand sediment. Hovem showed that the coupled differential equations describing wave propagation could be written in the form

$$\nabla^2(He-C\zeta) = \frac{\partial^2}{\partial t^2}(\rho e-\rho_f\xi) \quad , \tag{1}$$

and

$$\nabla^2(Ce-M\xi) = \frac{\partial^2}{\partial t^2}(\rho_f e-\rho_c\xi) - \frac{\eta}{B_o} F_r(\kappa)\frac{\partial\xi}{\partial t} \quad , \tag{2}$$

where

e = dilation of the skeletal frame,

ξ = relative dilation between frame and fluid,

ρ_f = bulk density of the pore fluid,

ρ_s = bulk density of the solid grains,

ρ_c = effective density parameter, and

ρ = bulk density of the aggregrate.

In turn, ρ is related to the solid and fluid densities by the porosity ϕ in the following equation:

$$\rho = (1-\phi)\rho_s + \phi\rho_f \quad . \tag{3}$$

The coefficients H, C, and M in Eqs. (1) and (2) are elastic coefficients related to the bulk modulus of the grains K_r, the shear modulus of the frame μ_b, the bulk modulus of the frame K_b, and the porosity ϕ as follows:

$$H = K + 4/3\ \mu_b \quad , \tag{4}$$

where

$$K = K_r(K_b+Q)/(K_r+Q) \quad , \tag{5}$$

$$Q = (K_f/\phi)(K_r-K_b)/(K_r-K_f) \quad , \tag{6}$$

$$C = QK_r/(K_r+Q) \quad , \tag{7}$$

and

$$M = CK_r/(K_r-K_b) \quad . \tag{8}$$

Hovem also showed that for this particular type of sediment the effective density parameter ρ_c could be described in terms of fluid density, porosity, and a structure constant, γ, by the following equation:

$$\rho_c = \frac{\rho_f}{\phi} (1+\gamma) \quad , \tag{9}$$

where

$$\gamma = 1 + (\eta\phi/B_o\rho_f) \; [F_i(\kappa)/\omega] \quad . \tag{10}$$

Here B_o is the permeability of the sediment and η is the absolute viscosity of the pore fluid. The permeability can be related to grain size d_m, porosity ϕ, and a pore size parameter k by the following equation:

$$B_o = (d_m^2/36\ k)[\phi^3/(1-\phi)^2] \quad . \tag{11}$$

The coefficient k is a function of the pore shape and tortuosity of the pores and, for a spherical grain sediment, has a value between 4 and 5.

Thus, Hovem was able to set up a model for wave propagation in a spherical grain sediment which required only grain size, grain density, porosity, fluid density, fluid viscosity, and the wave propagation frequency as inputs. In preliminary work, model predictions as a function of frequency were investigated and confirmed.[9]

In order to further test the model, investigation of the model predictions as functions of other variable parameters was required. Pore fluid viscosity was decided upon as the parameter to be studied since the viscosity of the fluid could be varied by changing the concentration of an aqueous solution of a material such as alcohol or glycerin. The results of that experiment are discussed in the next section.

C. Experimental Results

In order to vary the viscosity of the pore fluid in a sediment, it was decided to examine the feasibility of changing the concentration of an aqueous solution of a substance to produce a measurable change in viscosity with concentration. Both ethyl alcohol and glycerin have well known characteristics of viscosity and both are soluble in water. Handbook[10] values are available for viscosity as a function of both concentration and temperature for ethyl alcohol and glycerin. Figure 16 shows the variation of viscosity with concentration for both materials at a temperature of 20°C. Glycerin was selected over alcohol due to the fact that glycerin is less volatile than alcohol and would thus provide a more stable pore fluid over a period of time.

Although a variation of viscosity was the object of the experiment, other properties of the fluid such as bulk modulus and density will also be a function of concentration and will affect the acoustical properties of the fluid and of the sediment. Compressional wave velocity and attenuation data were obtained for the pore fluid alone to measure the change in acoustical properties as the concentration and viscosity were varied. Figure 17 shows the velocity data plotted against glycerin concentration while Fig. 18 shows the same data plotted as a function of viscosity. The measurements were made at a frequency of 114 kHz and no extra attenuation due to the presence of glycerin in the solution was observed.

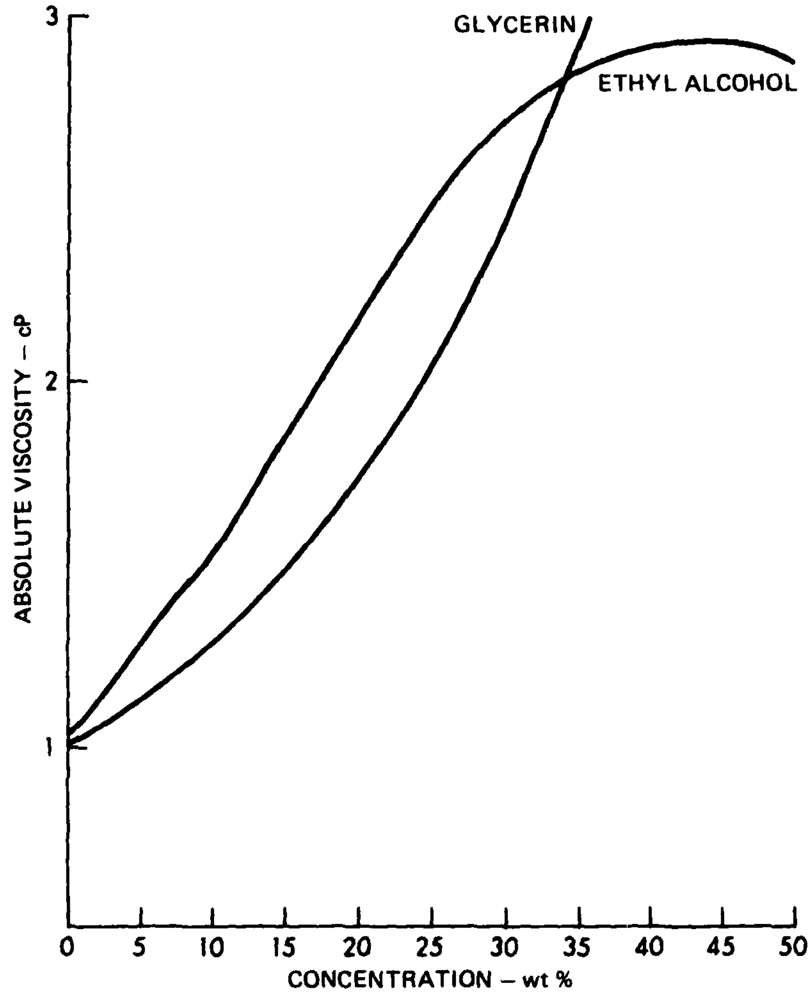

FIGURE 16
BEHAVIOR OF VISCOSITY AS A FUNCTION OF CONCENTRATION FOR AQUEOUS SOLUTIONS OF ETHYL ALCOHOL AND GLYCERIN

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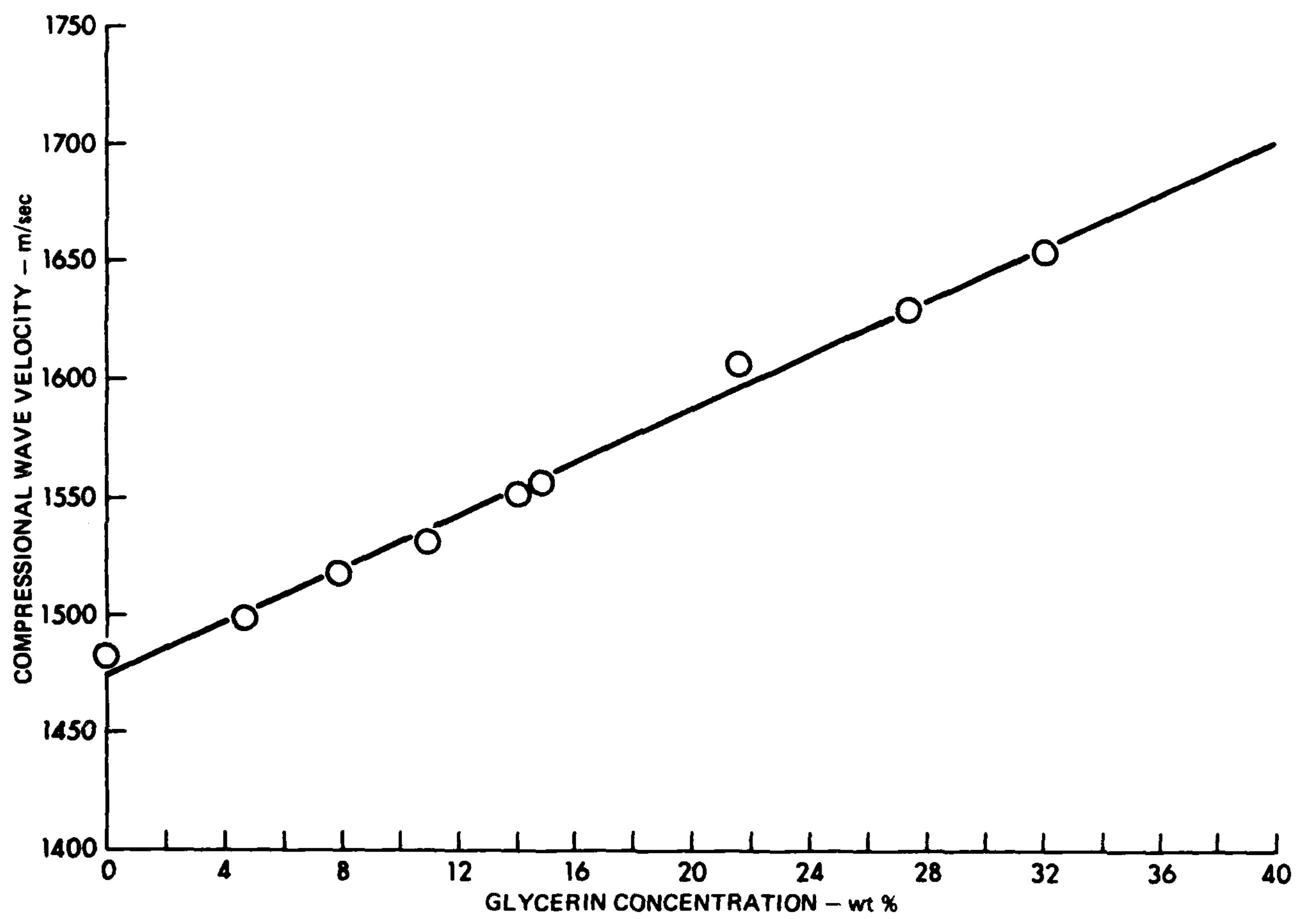

FIGURE 17
COMPRESSIONAL WAVE VELOCITY AS A FUNCTION OF GLYCERIN CONCENTRATION IN AN AQUEOUS SOLUTION

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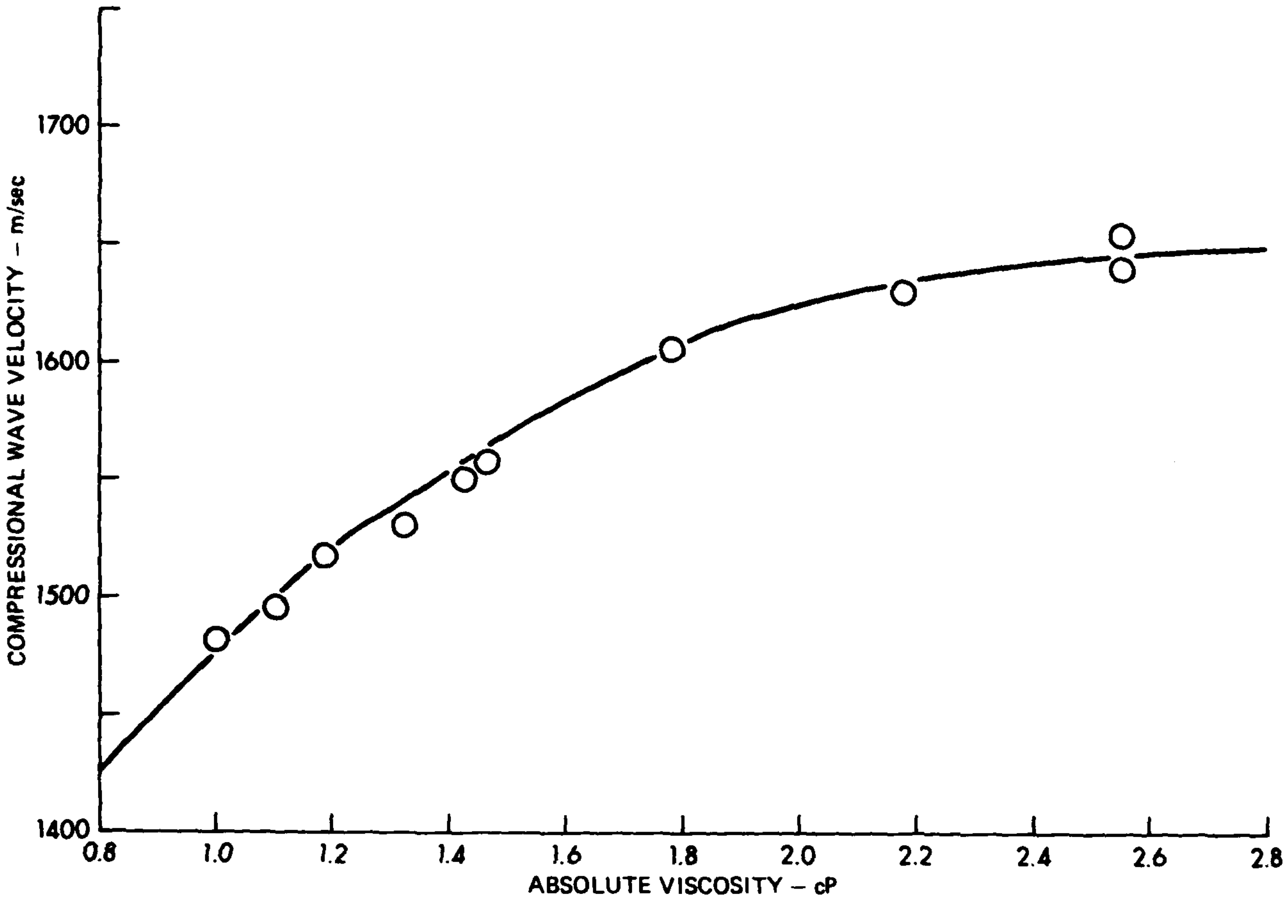

FIGURE 18
COMPRESSIONAL WAVE VELOCITY OF AN AQUEOUS SOLUTION OF GLYCERIN AS A FUNCTION OF VISCOSITY

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The velocity data were used in conjunction with handbook values for density of the solutions to calculate the bulk modulus for the material. The bulk modulus data are shown in Figs. 19 and 20 plotted as functions of concentration and viscosity. In each of the figures where data are plotted as a function of concentration, the data points are shown and the solid line is a least squares fit to the data. In the figures showing data plotted versus viscosity, the points are measured data while the solid lines are calculated from the least squares fit from the other figures. The bulk modulus obtained from the above data, as well as density and viscosity, is used in the analytical model to enable predictions of wave velocities and attenuations in a sediment with a pore fluid having the above properties.

A sediment consisting of spherical glass beads mixed with the above pore fluid was selected for study. Various physical properties of the sediment are listed in Table II. Calculations based on the work of Hovem[9] and Bell[8] were made of compressional wave velocity and attenuation and shear wave velocity and attenuation for the glass bead sand with variations in viscosity, saturated bulk density, and bulk modulus due to the changing properties of the pore fluid as the concentration of glycerin increased.

Measurements of compressional wave velocity and attenuation and shear wave velocity and attenuation were made in a small sediment tank 16 cm x 30 cm x 20 cm deep. The sediment sample was carefully prepared by adding demineralized water to the initially dry material, boiling the mixture, and then subjecting the cooled sediment to a vacuum for 24 hours. Once the sediment was ready for measurement, the transducers were inserted into the material and the apparatus allowed to remain undisturbed for another 24 hours. Acoustical measurements were then made and again the sediment was allowed to sit undisturbed for another 24 hours, after which the acoustical measurements were repeated. The above procedure was repeated until successive shear wave measurements were essentially identical. It was found that the sediment usually stabilized by the third or fourth 24 hour interval.

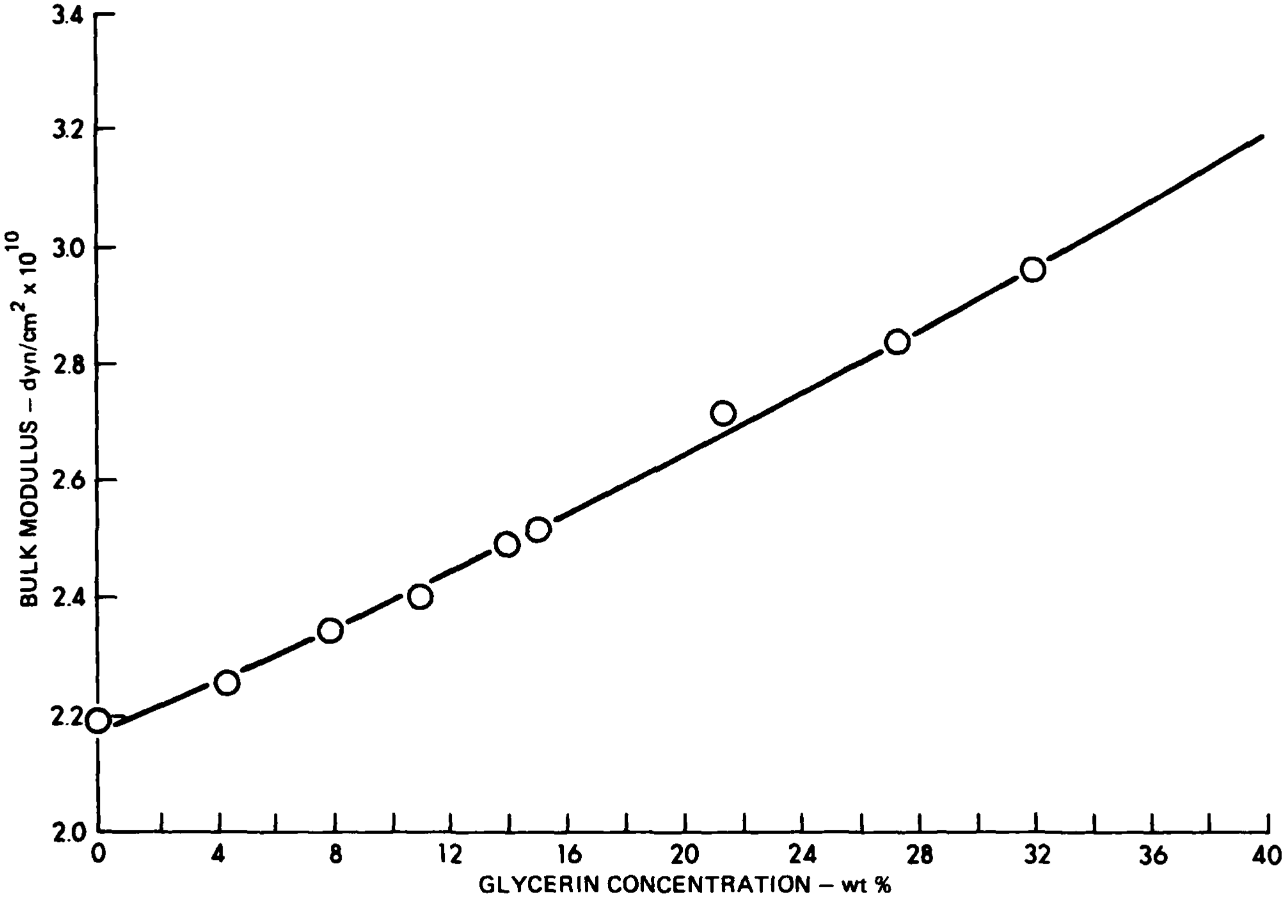

FIGURE 19
BULK MODULUS AS A FUNCTION OF GLYCERIN CONCENTRATION IN AN AQUEOUS SOLUTION

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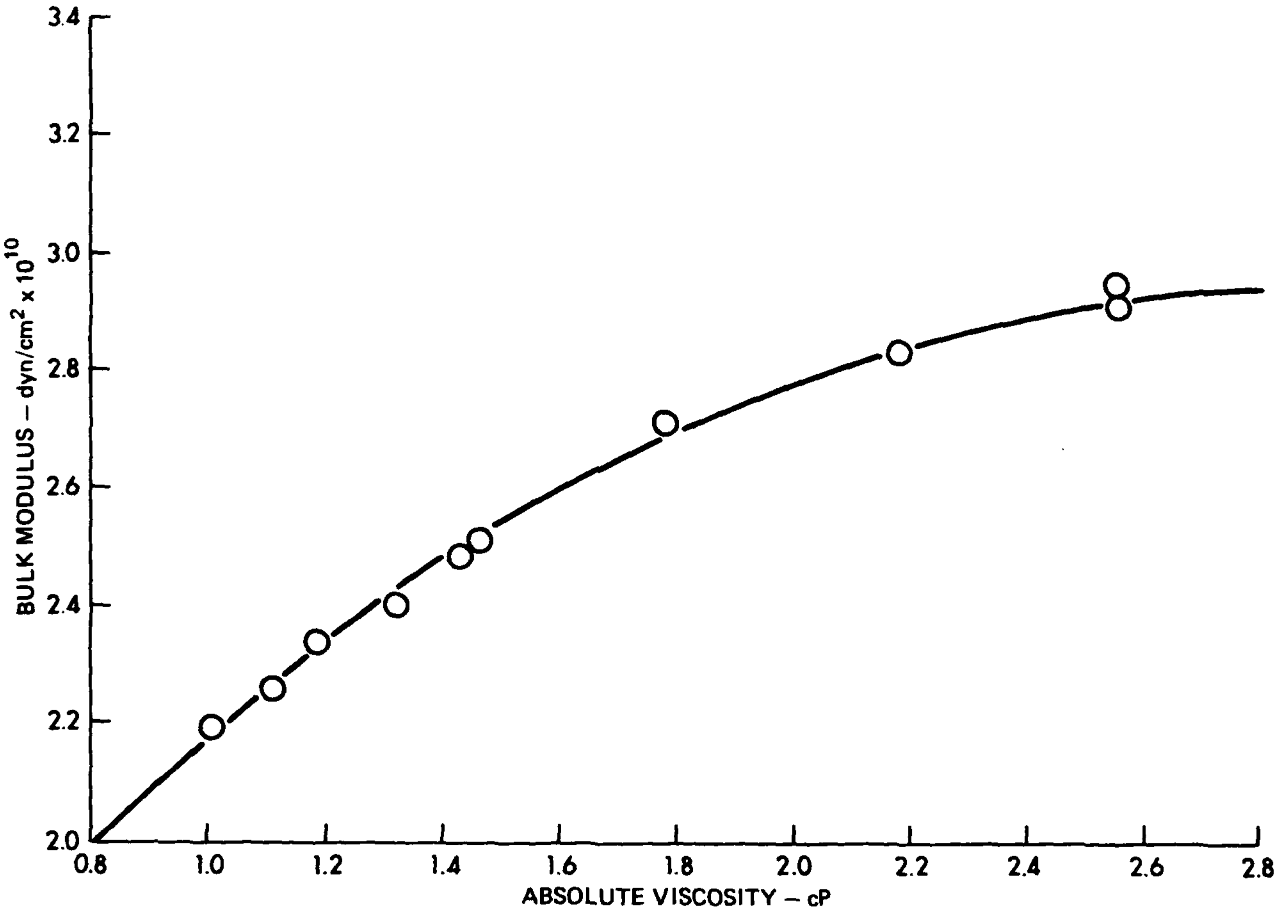

FIGURE 20
BULK MODULUS OF AN AQUEOUS SOLUTION OF GLYCERIN AS A FUNCTION OF VISCOSITY

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TABLE II

PHYSICAL PROPERTIES OF A GLASS BEAD SEDIMENT USED IN ANALYTICAL MODEL CALCULATIONS

Bead Type	MH
Grain Diameter	1.8×10^{-2} cm
Grain Density	2.50 g/cm^3
Grain Bulk Modulus	1×10^{12} dyn/cm^2
Porosity	0.365
Permeability	2.713×10^{-7} cm^2

Once a set of acoustical measurements had been made, the sediment was removed from the tank, approximately 400 ml of glycerin was added, and the new mixture was thoroughly stirred. The sediment was again evacuated to remove entrained air and the acoustical measurement procedure described above was repeated. After acoustical measurements were completed for a particular concentration of glycerin, a sample of the pore fluid was removed from the tank for viscosity and density measurements. Viscosity was measured at 20°C with a modified Ostwalt viscometer and density was measured at 20°C with a calibrated 50 ml pycnometer. The viscosity and density measurements were used to determine concentration. After successive measurements to a concentration of approximately 25% glycerin, the sediment was discarded and the whole procedure repeated as a check with freshly prepared sediment.

Transducers used to make the compressional and shear wave measurements were similar to those described previously,[11] and consisted of a shear wave bender element mounted so that the plane of the bender was vertical, and a small compressional wave element near the bender element. One projector was used with two receivers at different distances so that attenuation could be calculated from the difference in amplitude between the signals at the two receivers. Compressional wave data were obtained at a frequency of 114 kHz and shear wave data at a frequency of 2.8 kHz. Depth of the transducers in the sediment was approximately 10 cm.

Figure 21 shows the response of compressional wave velocity in the sediment to changes in the concentration of glycerin in the pore fluid. These changes in velocity are due mainly to changes in the sediment bulk modulus rather than to any dependence on viscosity. In any event, the predicted curve shows a greater slope than the data. Figure 22 shows that the same relationship holds true for shear wave velocity except that the difference in slope is slightly smaller.

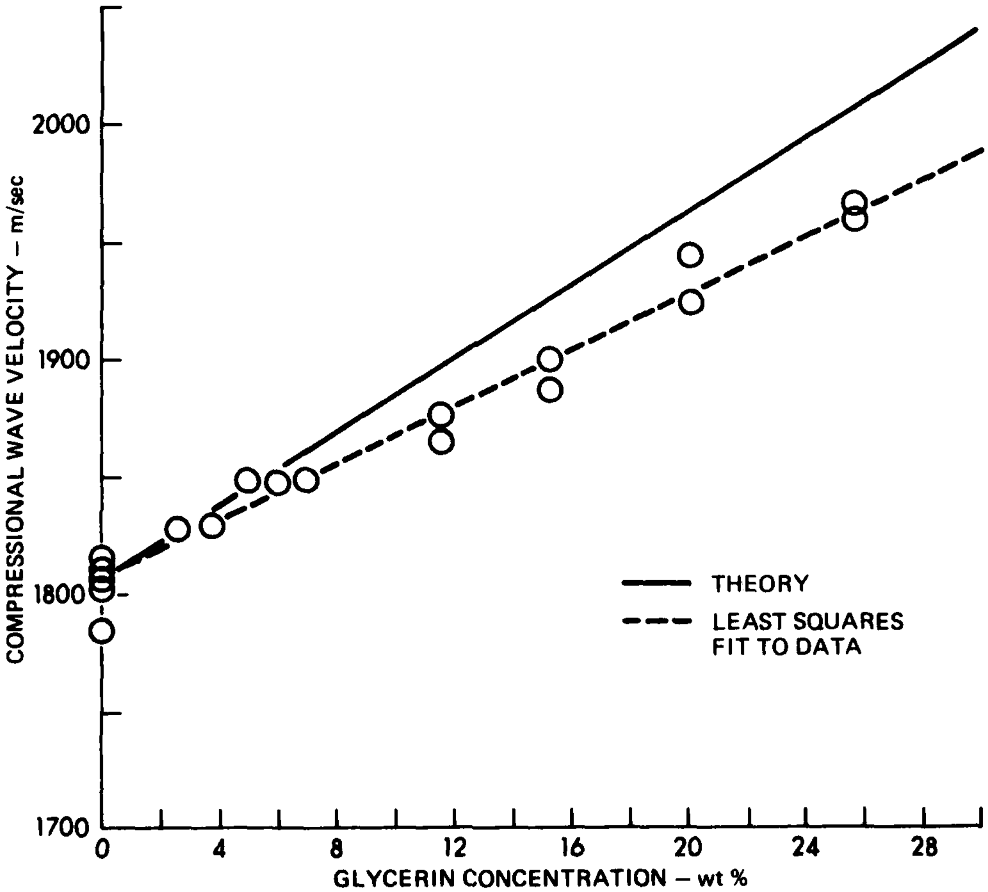

FIGURE 21
COMPRESSIONAL WAVE VELOCITY IN A GLASS BEAD SEDIMENT AS A FUNCTION OF GLYCERIN CONCENTRATION IN THE PORE FLUID

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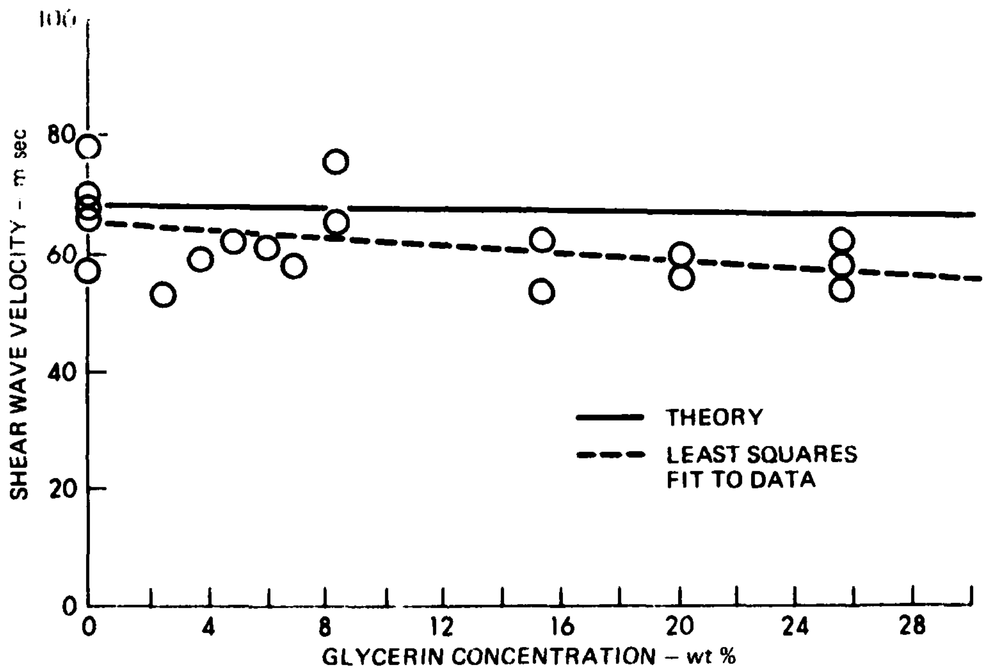

FIGURE 22
SHEAR WAVE VELOCITY IN A GLASS BEAD SEDIMENT AS A FUNCTION OF GLYCERIN CONCENTRATION IN THE PORE FLUID

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Differences between the theoretical predictions and the data also appear in the compressional wave and shear wave attenuations. Figures 23 and 24 show the compressional wave and shear wave data, respectively, compared to the model predictions. In these cases, the attenuations are larger than predicted for both wave types and also have larger slopes than predicted. It could be conjectured here that the viscous loss model does not accurately describe the situation where frame losses due to the lubricating action of the added glycerin can contribute significantly. For whatever reason, the model did not accurately predict acoustical parameters of a sediment for other than plain water as pore fluid.

Since the purpose of the experiment was to examine the effects of viscosity of the pore fluid, the attenuation data have also been plotted as a function of viscosity and are shown in Figs. 25 and 26. The least squares fit to the data from Figs. 23 and 24 have also been included for comparison, replotted for viscosity. It is not proposed here that a linear fit to the data as a function of glycerin concentration or of viscosity is appropriate since the scatter in the data is too large for an accurate determination.

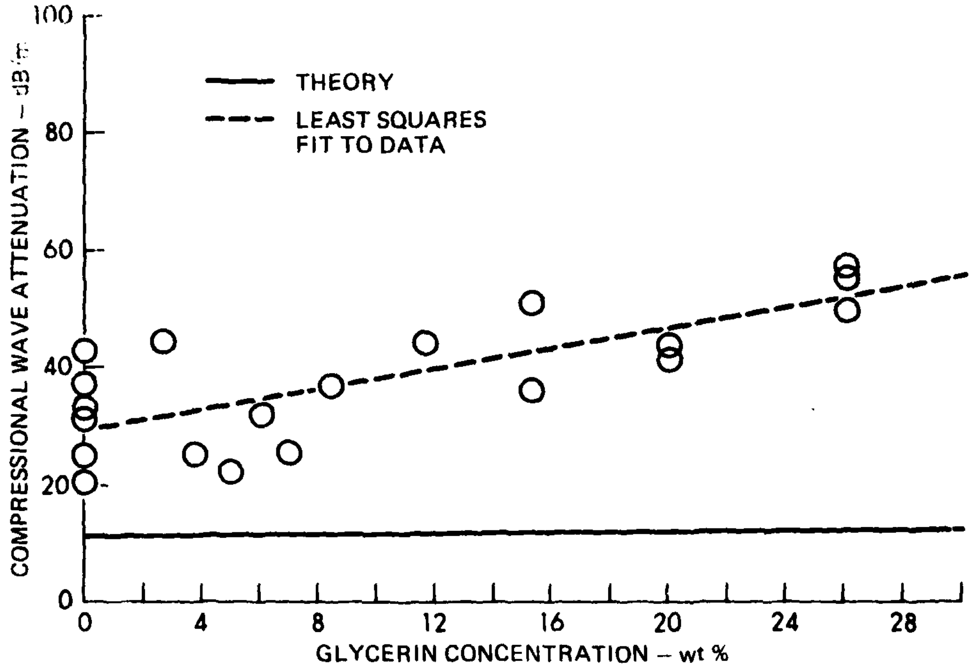

FIGURE 23
COMPRESSIONAL WAVE ATTENUATION AS A FUNCTION OF GLYCERIN CONCENTRATION IN A GLASS BEAD SEDIMENT
f_0 = 114 kHz

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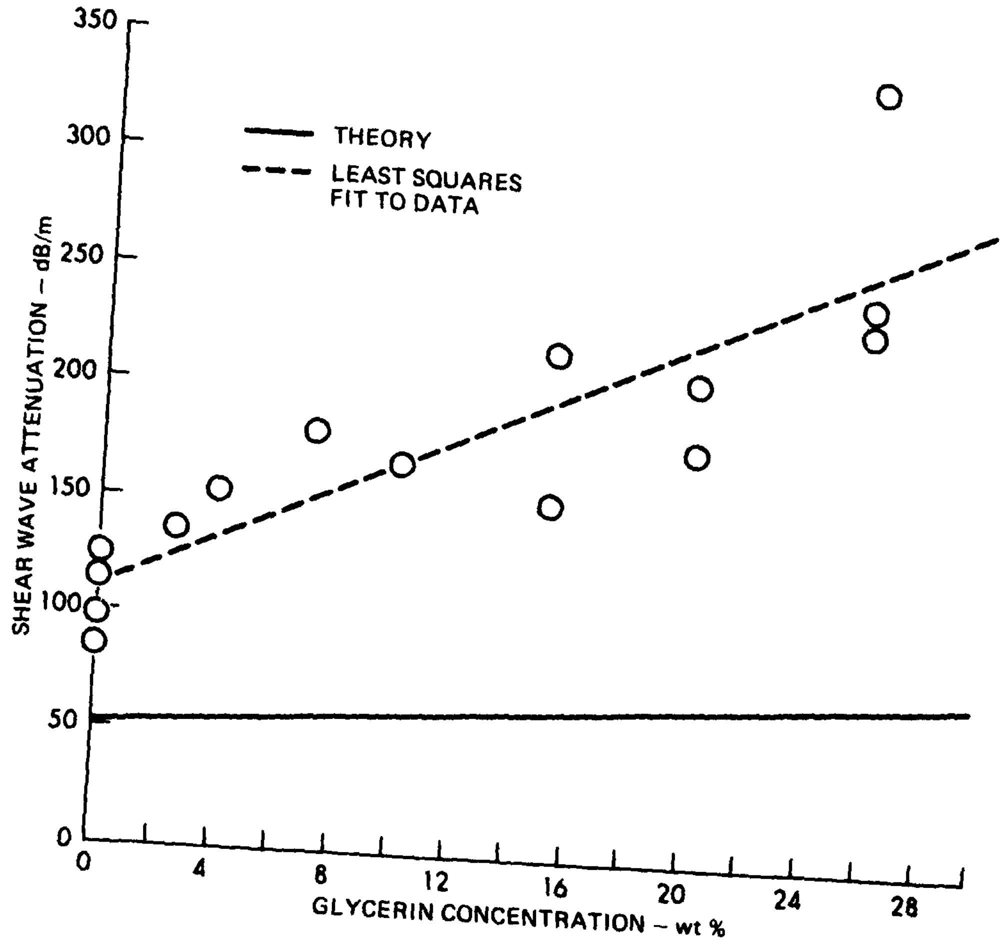

FIGURE 24
SHEAR WAVE ATTENUATION AS A FUNCTION OF GLYCERIN CONCENTRATION IN A GLASS BEAD SEDIMENT
$f_0 = 2.8$ kHz

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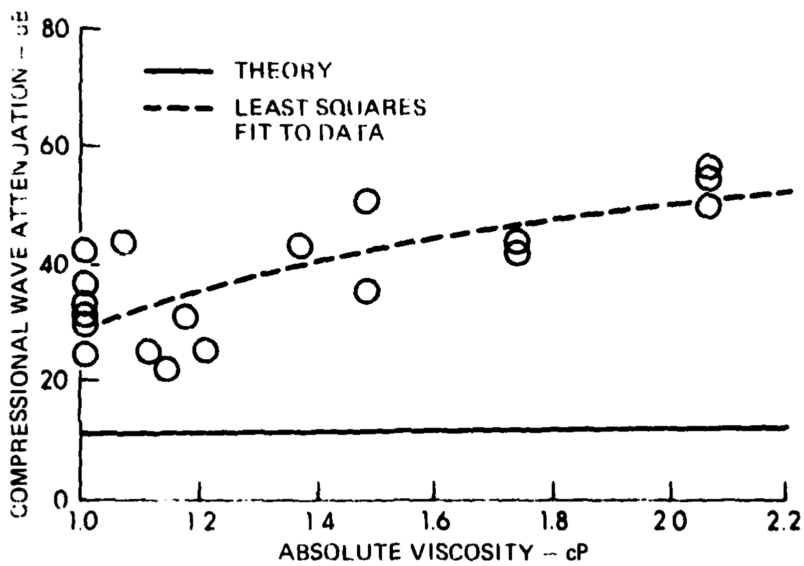

FIGURE 25
COMPRESSIONAL WAVE ATTENUATION versus VISCOSITY IN A GLASS BEAD SEDIMENT SATURATED WITH WATER-GLYCERIN MIXTURE
f_0 = 114 kHz

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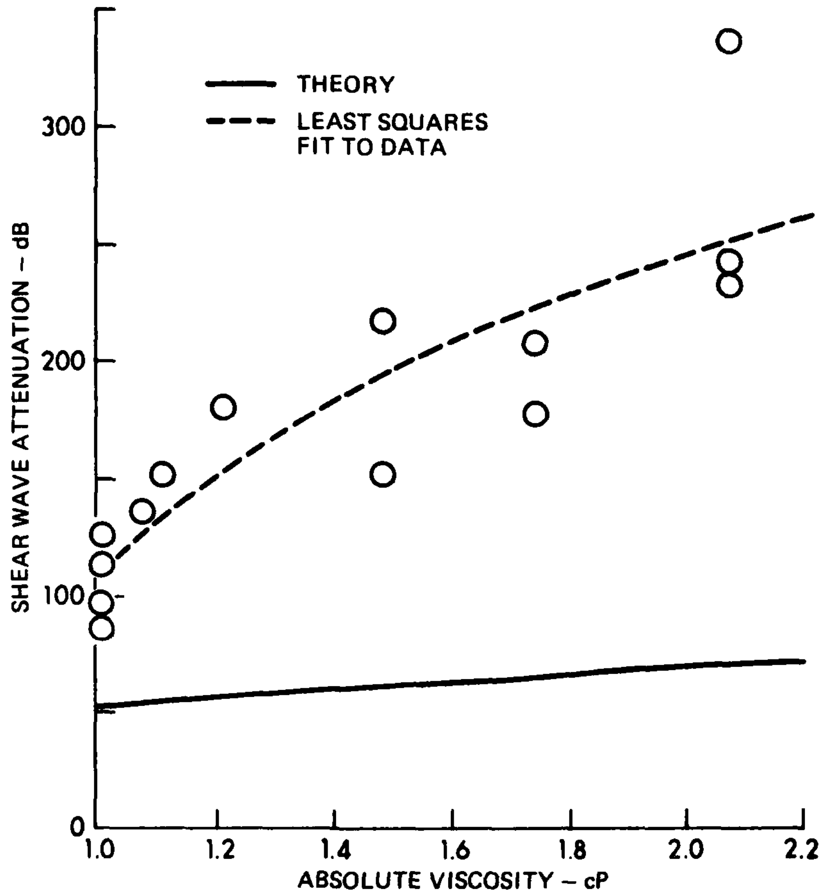

FIGURE 26
SHEAR WAVE ATTENUATION *versus* VISCOSITY IN A GLASS BEAD SEDIMENT SATURATED WITH WATER-GLYCERIN MIXTURE
f_0 = 2.8 kHz

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IV. SUMMARY

During the past year, the ARL:UT sediment acoustics program has been involved in two areas of work.

1. The in situ acoustic measuring system has been reconfigured to enable concurrent measurement of compressional wave velocity and attenuation, shear wave velocity and attenuation, and acoustic impedance. The recording instrument and transducers have been successfully tested in the laboratory and are being prepared for extensive field testing.
2. A laboratory experiment has been concluded to test predictions of the analytical model developed by Hovem. Viscosity of the pore fluid in an artificial sediment of spherical glass beads was varied by mixing various concentrations of glycerin with water. Results of the experiment indicate that predictions of the model do not match measured data. Further examination and modification of the model, plus repeat of the measurements, are indicated.

Future work under the program will continue to emphasize a balance between analytical modeling, laboratory measurements, and in situ measurements to ensure accurate results. Topics to be investigated include:

1. theoretical model development,
2. physical scale model development,
3. investigation of interface waves,
4. investigation of nonlinear acoustical parameters of sediments,
5. examination of Biot's second type compressional wave,
6. investigation of the effects of salinity on sediment acoustical properties,
7. investigation of the relationship between engineering properties and acoustical properties of sediments,

8. investigation of the density profile and compressional wave/ shear wave velocity ratio in situ,

9. development of a free-fall sediment acoustic measuring system, and

10. development of a shear wave acoustic reflection profiler system.

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APPENDIX A

Introduction

The purpose of this appendix is to provide detailed circuit descriptions and schematics of the new or revised analog measuring circuits of the profilometer and the new solid state memory which was developed to replace the FM magnetic tape recording system. Included in the analog circuits are (1) a revised pulse generator circuit, (2) a circuit to measure acoustic impedance, and (3) a circuit to measure shear strength. In the digital category are (1) a controller and digitizer for the solid state memory, (2) the memory circuits, and (3) a computer interface to couple stored digital data into the microcomputer.

Pulse Generator

Figure 27 is a schematic diagram of the revised pulse generator circuit used to drive the acoustic transducers to make both compressional and shear wave measurements in the profilometer. The original circuit operated at its own repetition (200 pps) rate to generate a positive going square pulse of the proper length (2.5 μsec for compressional waves, 250 μsec for shear waves). The new circuit described here is almost identical except that the repetition rate is controlled by a trigger input from the solid state memory circuits and generates the pulse at a controlled time interval following the trigger. Compressional wave and shear wave circuits are identical except for the RC network used to control pulse width.

Referring to Fig. 27, U1 is a CD4098 dual monostable integrated circuit, part of which is used to generate a constant delay after the trigger, and the other, to generate the driving pulse. The trigger

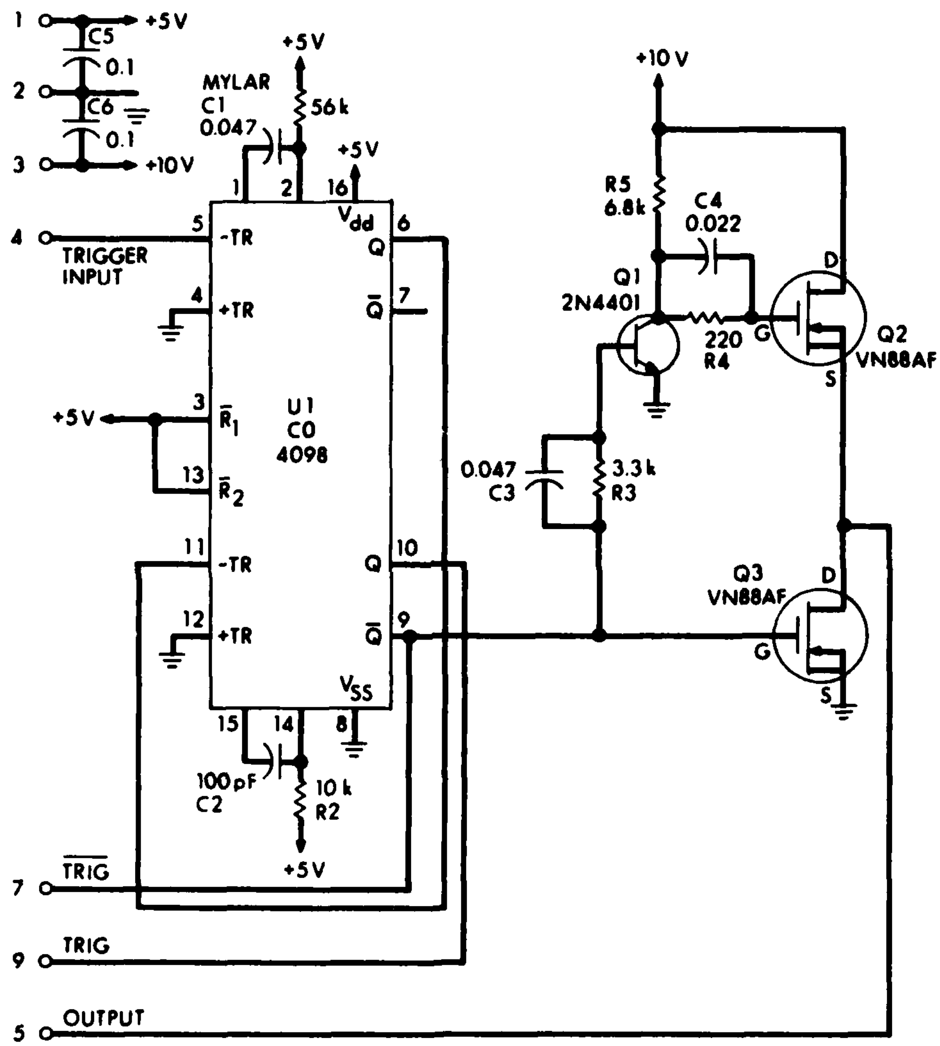

FIGURE 27
SCHEMATIC DIAGRAM OF THE PULSE GENERATOR

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input to pin 5 of U1 triggers the monostable on the trailing edge of the trigger pulse. A positive going pulse is generated at the Q output of the monostable, pin 6. The length of the pulse and consequently the delay is controlled by R1 and C1. If no delay is desired, C1 is removed and pin 2 of U1 is connected directly to +5 V. The delay pulse from pin 6 of U1 is coupled into the negative trigger input of the second monostable at pin 11 so that the second monostable is triggered on the trailing edge of the delay pulse. Complementary pulses are generated at the Q and $\overline{Q}$ outputs of U1 and are provided to the card edge connector for triggering other circuits in the profilometer. Pulse width of the second pulse is controlled by the time constant of R2 and C2. Values shown in Fig. 27 are for a 2.5 μsec pulse for compressional wave measurements. Changing C2 to a value of 0.01 μF will provide a 250 μsec pulse appropriate for shear wave measurements.

The $\overline{Q}$ output from the second monostable is applied to the base of transistor Q1, which is configured as a common emitter amplifier. The negative going pulse is inverted and amplified from the nominal 5 V level to a 10 V level and applied to transistor Q2 which is a VMOS power FET arranged in a source-follower circuit to drive the output. Q3 is an identical power FET used as a switch to connect the output line to ground when the driving pulse is not applied. Operation in this manner reduces ringing in the acoustic transducer.

Acoustic Impedance Measurement Circuit

The purpose of the acoustic impedance measuring circuit is to provide a continuous wave (cw) signal to the acoustic impedance transducer at the resonance frequency of that transducer when it is immersed in water, and to detect and amplify the analog voltage from the circuits associated with the transducer which detect the current through the transducer.

Figure 28 is the schematic diagram of the part of the acoustic impedance circuit which is in the pressure case while Fig. 29 shows the schematic diagram for the circuits associated with the transducer.

Referring to Fig. 28, U1 is an NE566 function generator integrated circuit configured to generate a constant frequency, constant amplitude triangular wave signal at pin 4. The frequency of oscillation is controlled by the time constant of R3 and C2 and the frequency can be varied by adjusting R3. The signal is coupled to U2 where it is amplified and then applied to the transducer cable through R7. The series resistance of R7 is used to decouple the cable capacitance from the operational amplifier U2 and thus maintain stability. The analog signal which is proportional to the transducer impedance is filtered by R8, R9, and C4 and applied to the operational amplifier U3 which amplifies the signal by a factor of 10.

In Fig. 29, U4A is used to buffer the signal coming through the cable from the generating circuit and to drive the transducer element at a constant voltage level. R1 senses the current through the element and develops an ac voltage inversely proportional to the impedance of the element. The ac signal from R1 is rectified by U4B which is an operational amplifier configured as a half-wave rectifier circuit. The rectified signal then goes back up the cable to be filtered and amplified and applied to the recording circuits.

Shear Strength Measuring Circuit

The purpose of the shear strength measuring circuits is to provide a dc excitation voltage to the strain gauge bridge elements on the transducer and to measure the resulting bridge output voltage, amplify it, and provide it to the recording circuits. Figure 30 shows the schematic diagram of the circuit. SG1 and SG2 are metal strain gauges mounted on opposite sides of a cantilever bar (see Section II.C) used

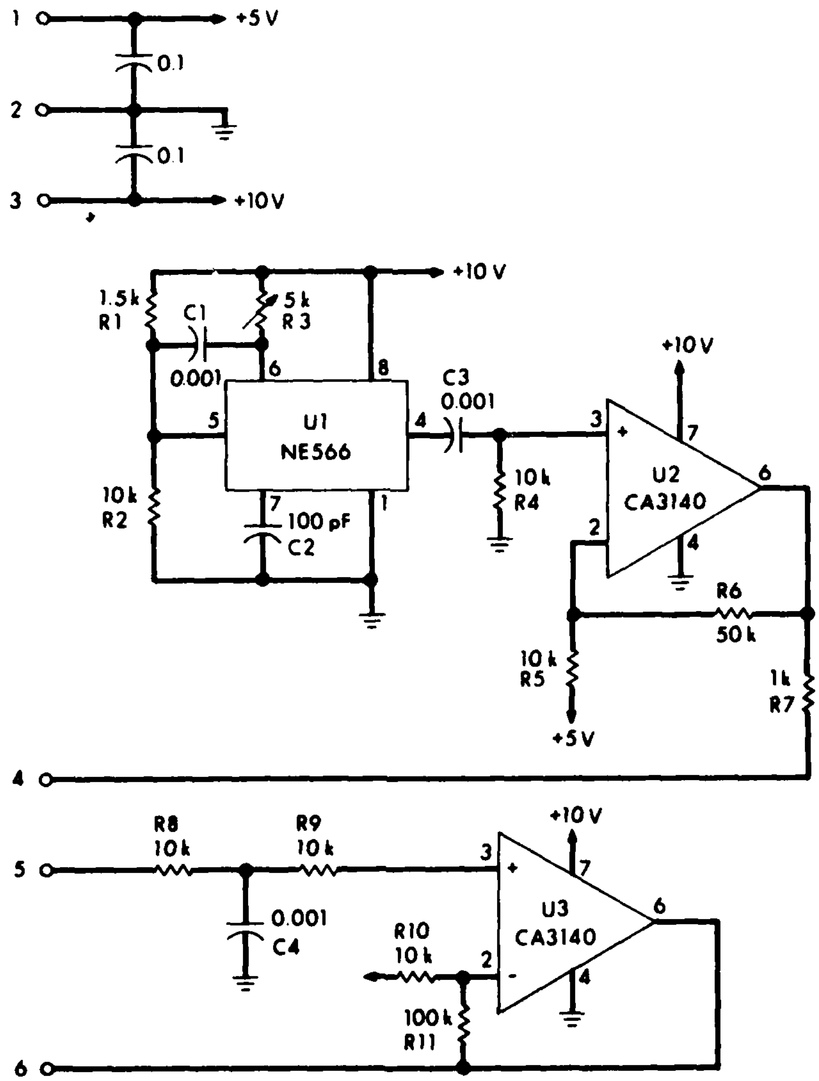

FIGURE 28
SCHEMATIC DIAGRAM OF THE ACOUSTIC IMPEDANCE MEASURING CIRCUIT

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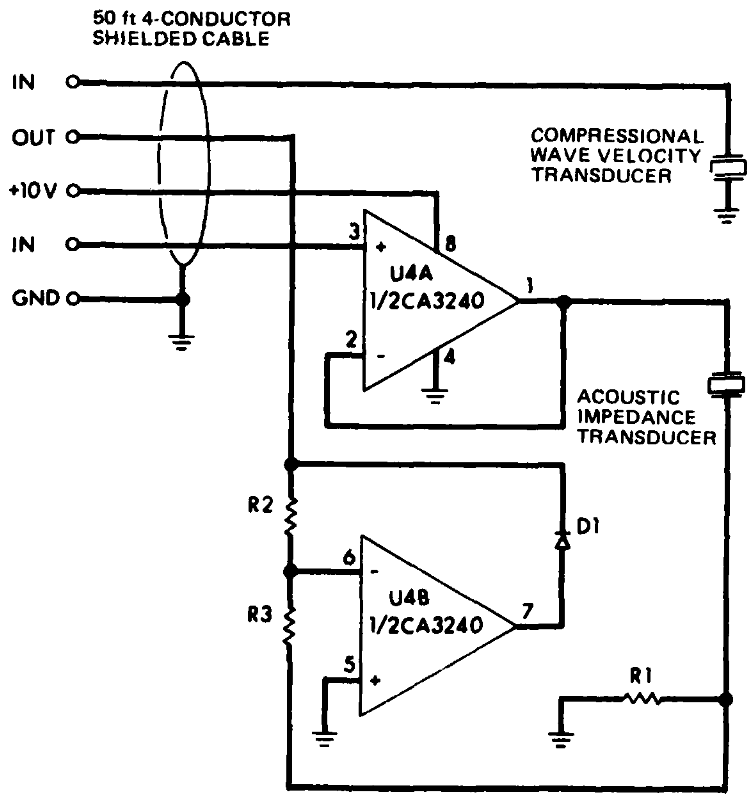

FIGURE 29
SCHEMATIC DIAGRAM OF THE ACOUSTIC IMPEDANCE TRANSDUCER CIRCUIT

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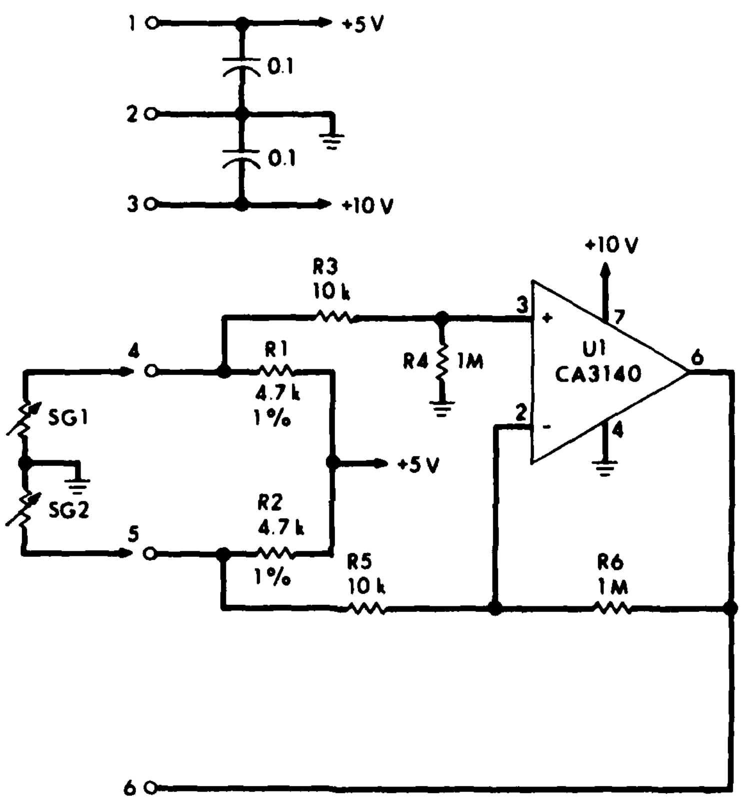

FIGURE 30
SCHEMATIC DIAGRAM OF THE SHEAR STRENGTH MEASURING CIRCUIT

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to sense the force exerted on a penetrometer body attached to the end of the bar. The strain gauges are arranged such that forces on the penetrometer bend the bar and cause one strain gauge to increase in resistance and the other to decrease in resistance by the same amount. The two strain gauges form a bridge network with R1 and R2 to detect the strain gauge resistance changes. The output of the bridge is connected to U1 which is an operational amplifier connected as a differential input amplifier with a voltage gain of 100. The output of the amplifier is provided through the card edge connector to the recorder circuits.

Solid State Memory Controller

The solid state memory controller includes circuits to multiplex six data channels, digitize the analog data, provide chip selects and address signals to the memory, and provide appropriate timing signals to control the operation sequence of all the circuit units in the profilometer.

Figure 31 is the schematic diagram of the control and digitizing circuits. Figure 32 provides a timing diagram of those circuits. The circuits comprise the following individual sections:

(1) recorder on-off control,
(2) clock generator and divider,
(3) input channel multiplexer,
(4) sample-and-hold amplifier,
(5) channel select counter,
(6) A/D converter,
(7) address counter, and
(8) chip select control.

The four sections of U15 constitute the recorder on-off control circuit. A free-fall sensing switch located exterior to the pressure case is connected to the input (pins 1 and 2) of NOR gate U15A connected

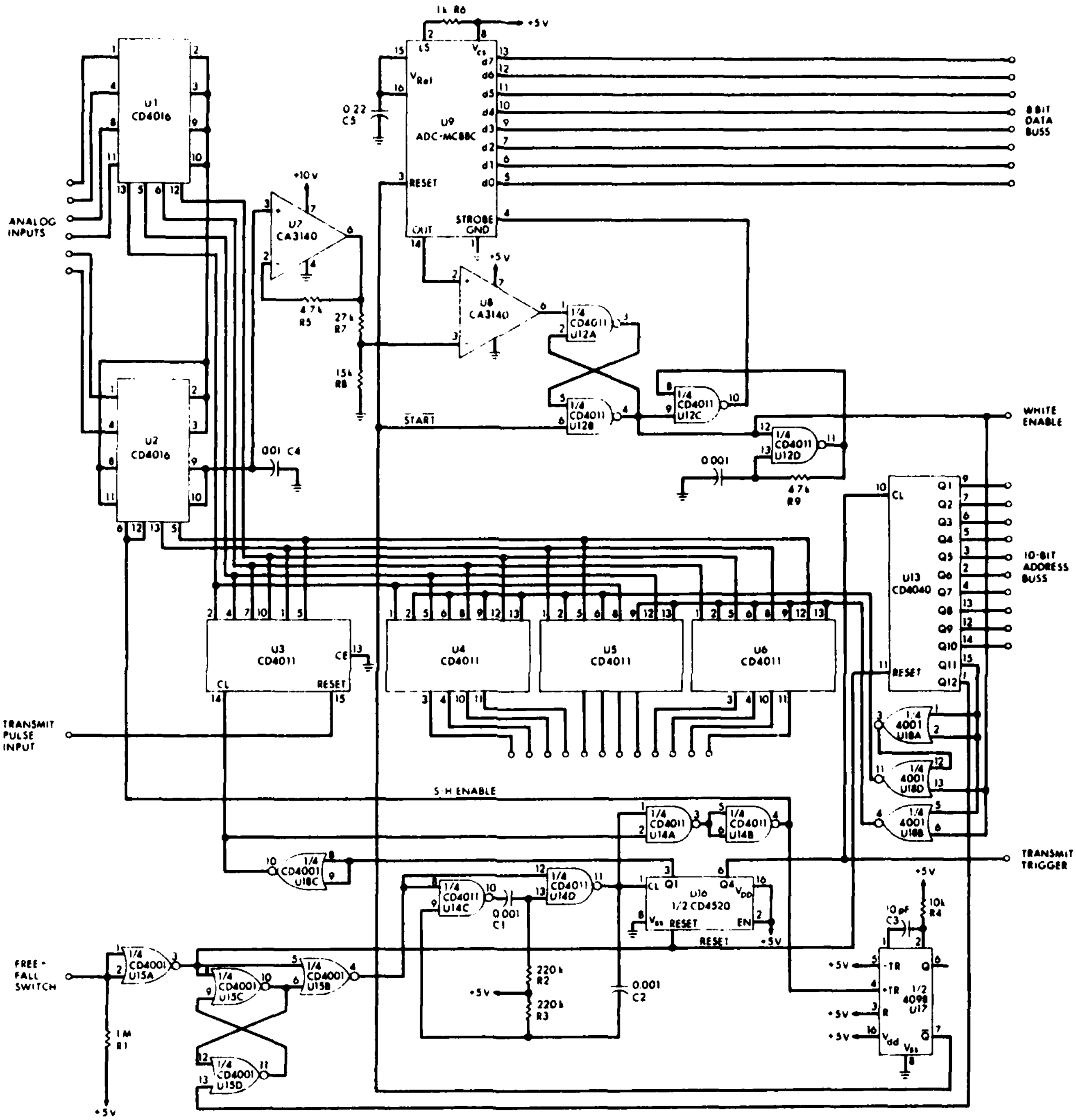

FIGURE 31
SCHEMATIC DIAGRAM OF THE DIGITAL MEMORY CONTROL CIRCUIT

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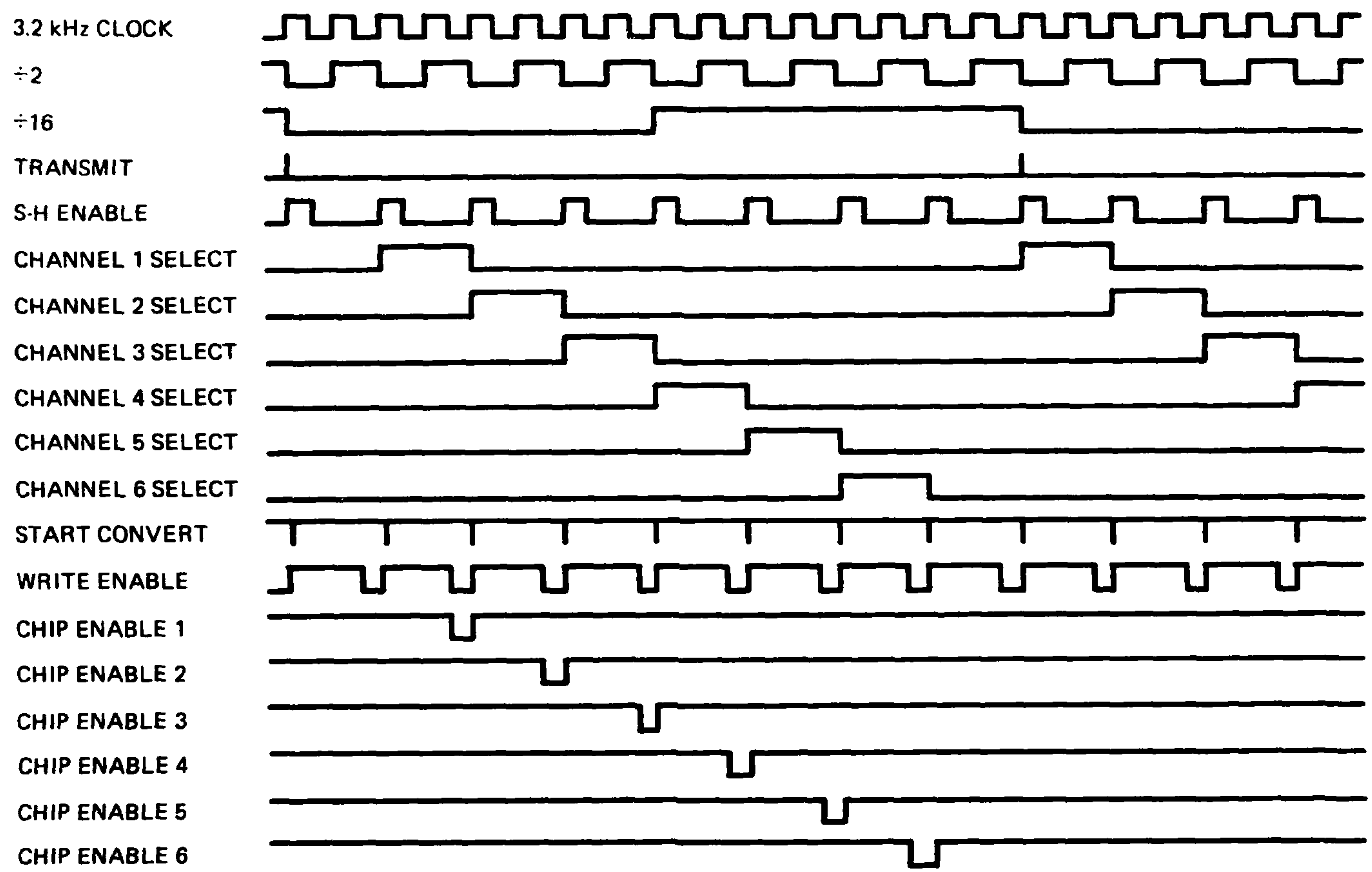

FIGURE 32
TIMING DIAGRAM FOR THE DIGITAL MEMORY CONTROL CIRCUITS

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as an inverter. The switch is a normally closed magnetic reed switch which is caused to open when the corer is triggered at the ocean bottom. While the switch is closed, the input to U15A is low so the output will be high. The output line is connected to the reset inputs of counters U16 and U13 which causes their outputs to be low. The output of U15A is also connected to one input (pin 8) of an R-S flip-flop composed of U15C and U15D. Since the other input (pin 13) is connected to an output of counter U13, which is held low by the high reset input, the output of the R-S flip-flop (pin 10) is high. The output of the R-S flip-flop and the reset line are NOR'ed in U15B and with both inputs high the output of U15B is held low. The output from U15B is used to control a gated 3.2 kHz oscillator composed of U14C and U14D and associated RC networks. When the output from U15B is low, the oscillator is off and digitizing and storage of data is inhibited. When the free-fall reed switch is opened at the start of corer free-fall, the reset line is caused to go low, which enables counters U16 and U13 and brings the outputs of U15B high to enable the 3.2 kHz oscillator. The R-S flip-flop remains in its initial state. Counter U16 divides the 3.2 kHz from the oscillator and provides the ÷2 and ÷16 signals as outputs. These clock signals are shown at the top of the timing diagram, Fig. 32. The ÷16 clock pulse is input to the pulse generator in the analog measuring circuits where the falling edge of the ÷16 clock pulse initiates the generation of an acoustic pulse and the resultant measurement of the acoustic velocities. The ÷16 pulse is also input to the clock of 14-stage counter U13. The first 10 outputs of U13 are used as the address bus for the digital memory circuits. As a result, each time an acoustical measurement is initiated by the ÷16 clock pulse, the digital memory is advanced to the next location for storage of the six data bytes associated with each measurement.

The ÷2 clock pulse from U16 is inverted by U18C and supplied as the clock pulse to decimal counter U3. The outputs of counter U3 are decoded to provide a single positive going pulse at one of its 10 outputs, starting at Q0 and going to Q9 each time the counter is clocked. During reset, Q0 goes high. Six of the outputs of U3 (Q1 through Q6)

are used as the channel select signals and are shown in Fig. 32. The inverted ÷2 clock pulse going to U3 is also AND'ed with the 3.2 kHz main clock signal by NAND gates U14A and U14B to produce the sample-and-hold enable pulse. When this pulse is high, the sample-and-hold amplifier samples the level of the selected analog signal and when the pulse goes low the analog level is held constant by the amplifier.

The analog multiplexer and the sample-and-hold gate are implemented in the two CD4016 analog gate IC's, U1 and U2. The gates operate as single-pole/single-throw switches controlled by the outputs of U3 and the sample-and-hold signal. The multiplexer sequentially connects each of the six inputs to the sample-and-hold switch. Immediately after each input is connected, the sample-and-hold switch is closed and allows sampling capacitor C4 to charge to the analog voltage level. U7 is an operational amplifier connected as a X1 gain buffer to keep the load of following circuits from discharging C4.

As each of the six analog inputs is selected by the outputs of counter U3, one of six digital memory chips must be selected for storage of that datum. There are a total of 12 memory chips, two for each of the analog channels. The data from each channel is stored in each chip by selecting that chip through a low level CHIP ENABLE ($\overline{CE}$) input. After cycling through the six inputs and six chips, the addresses for all memory chips are advanced by clocking address counter U13. After a set of six chips are filled with data (1024 bytes) all 10 address lines (Q1 through Q10 of U13) will be high. The next clock pulse into U13 will set all address lines low again and set Q11 of U13 high. This action will select the next bank of six memory chips for storage.

The low going $\overline{CE}$ pulses are generated from the high going channel select signals by first NOR'ing the Q11 output from U13 in NOR gates U18B and U18D with the WRITE ENABLE ($\overline{WE}$) pulse from the A/D converter and NAND'ing the result with the channel select signals in NAND gates U4, U5, and U6. Both the noninverted and inverted versions of the Q11

output of U13 are used in this way so that when Q11 is low, the first six $\overline{\text{CE}}$ signals are enabled and when Q11 is high, the other six $\overline{\text{CE}}$ signals are enabled and the first six are disabled.

After each of the six input channels is selected, a short, low going pulse is generated which is used to initiate the analog-to-digital conversion. The leading edge of the sample-and-hold enable pulse is applied to the trigger input of monostable multivibrator U17. The $\overline{\text{Q}}$ output of U17 is a low going pulse whose duration is controlled by the RC time constant of R4 and C3. The output pulse is applied to the reset input of the analog-to-digital converter (ADC) chip U9 which sets all eight bits of its output low. The start pulse is also applied to one input of R-S flip-flop formed by U12A and U12B and sets the output of the flip-flop high. This output is used as the END OF CONVERSION ($\overline{\text{EOC}}$) signal and also as the WRITE ENABLE ($\overline{\text{WE}}$) signal. When $\overline{\text{EOC}}$ is high, the ADC is busy converting and output data are not valid.

The input of the ADC is connected through resistance R7 and R8 to the output of the sample-and-hold amplifier. R7 and R8 are used to set the calibration of the unit so that 5 V input will produce a digital output from the ADC with all bits high. With zero input, all bits from the ADC will be low. The input voltage is connected to the noninverting input of operational amplifier U9 which is configured as a voltage comparator. The inverting input of the comparator is connected to the analog output of the ADC chip.

At the start of conversion when $\overline{\text{EOC}}$ goes high, a 500 kHz clock generator formed by U12C and U12D is enabled and provides a 500 kHz pulse string to the strobe input (pin 4 of U9) of the ADC. As the counters internal to the ADC are incremented by the strobe input, an internal digital-to-analog converter (DAC) circuit provides a linearly increasing voltage at the analog output, pin 14. When the ADC output voltage reaches the same level as the input voltage, voltage comparator U8 switches its output low which resets the RS flip-flop (U12A and B) which in turn disables the ADC clock circuit, stops the ADC counters, and

sets $\overline{EOC}$ and $\overline{WE}$ low. The result is that the digital output of the ADC counters available on the eight data lines is directly proportional to the analog input voltage. The $\overline{WE}$ pulse is then used to store the data word in an appropriate space in the digital memory.

After 2048 samples of data have been obtained for each of the six inputs, Q12 of address counter U13 will go high. Q12 is connected to the reset input of RS flip-flop U15C and U15D. Pin 10 of U15 will return to a high level bringing pin 4 low and thus turning off the 3.2 kHz oscillator. With the oscillator disabled, the profilometer circuits cannot function and operation is effectively halted.

Solid State Memory Circuit

Figure 33 shows the schematic diagram of one of three identical memory boards used in the profilometer recorder. Each board carries four memory chips, which is sufficient for two channels of data. The data lines (D0 through D7) and the address lines (A0 through A9) are connected in parallel to all 12 chips in the memory circuit. The 12 $\overline{CE}$ lines are connected to the 12 outputs of the control circuit and to the $\overline{CE}$ inputs of the memory chips. The $\overline{WE}$ line is connected to all 12 chips and in conjunction with the $\overline{CE}$ signals determines where each digital datum will be stored.

Memory Power Supply

Power for most of the control and digitizing operations is supplied by the profilometer power unit. However, the operating time for the profilometer main battery is limited to about 18 h; it will also be disconnected when the unit is lifted out of the water upon retrieval. If power is lost, all data stored in the memory will also be lost. For this reason, the memory chips and selected portions of the control circuitry are operated from a separate battery system.

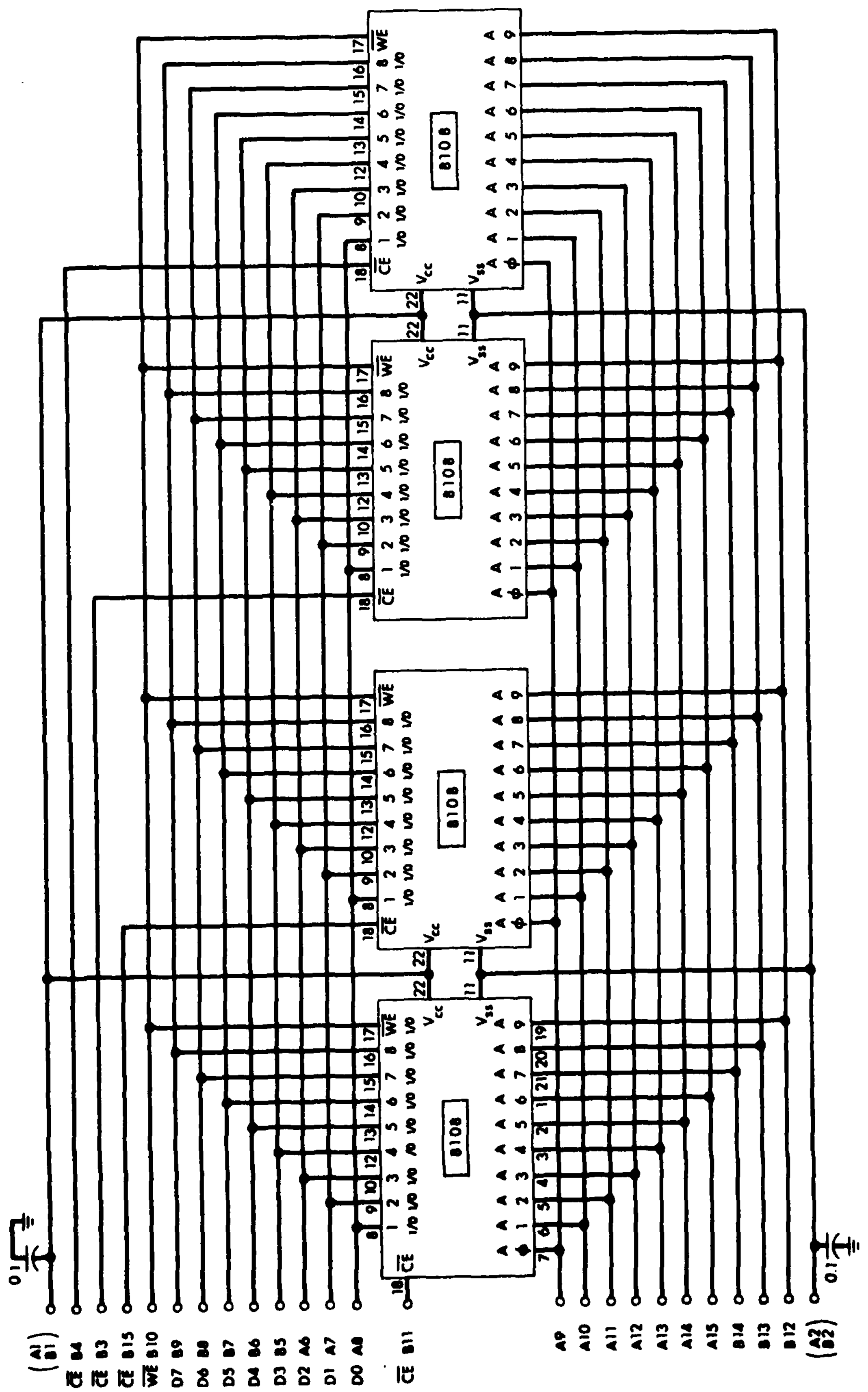

FIGURE 33
SCHEMATIC DIAGRAM OF THE DIGITAL MEMORY BOARD

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Figure 34 is the schematic of the memory power supply. Power is supplied by a 7.2 V, 1.8 A•h NiCad battery pack. Q1 is a silicon controlled rectifier (SCR) which acts as a power switch and keeps power to the memory circuits turned off until the unit is deployed. As the profilometer unit is immersed in the ocean, a saltwater sensor turns on the main power supply in the profilometer. The +5 V level on the main power bus turns on the SCR and thus applies power to the memory circuits. Once turned on, the SCR will remain on regardless of whether the main supply remains on or not. The battery pack is able to supply power to the memory for a period of 70 h.

The circuit composed of Q2, R3, D1, D2, C1, and C2 is a low power voltage regulator to regulate the battery voltage to the +5 V level required by the memory chips.

To ensure that data are retained in memory and that minimum power is used, the $\overline{CE}$ inputs to all the memory chips must be kept at a high level at all times except during the actual storage time interval. R4 through R15 are used to ensure that all $\overline{CE}$ inputs are pulled up to the +5 V supply rail even if other parts of the control circuit are disabled. For the same reason, the memory power supply is used to supply power to the board that contains the chip enable gates U4, U5, and U6.

Computer Interface

Once the profilometer has been deployed, and has recorded data and been retrieved, the data must be removed from the digital memory circuits inside the profilometer and stored in memory inside the minicomputer unit. To accomplish the transfer of digital data, the two printed circuit cards containing the multiplexer-A/D converter circuit and the address counter/channel select counter circuits are removed from the card cage of the profilometer recording unit, and two other printed circuit cards, which are attached by electrical cable to the microcomputer playback unit, are inserted in their place. The new cards generate address and

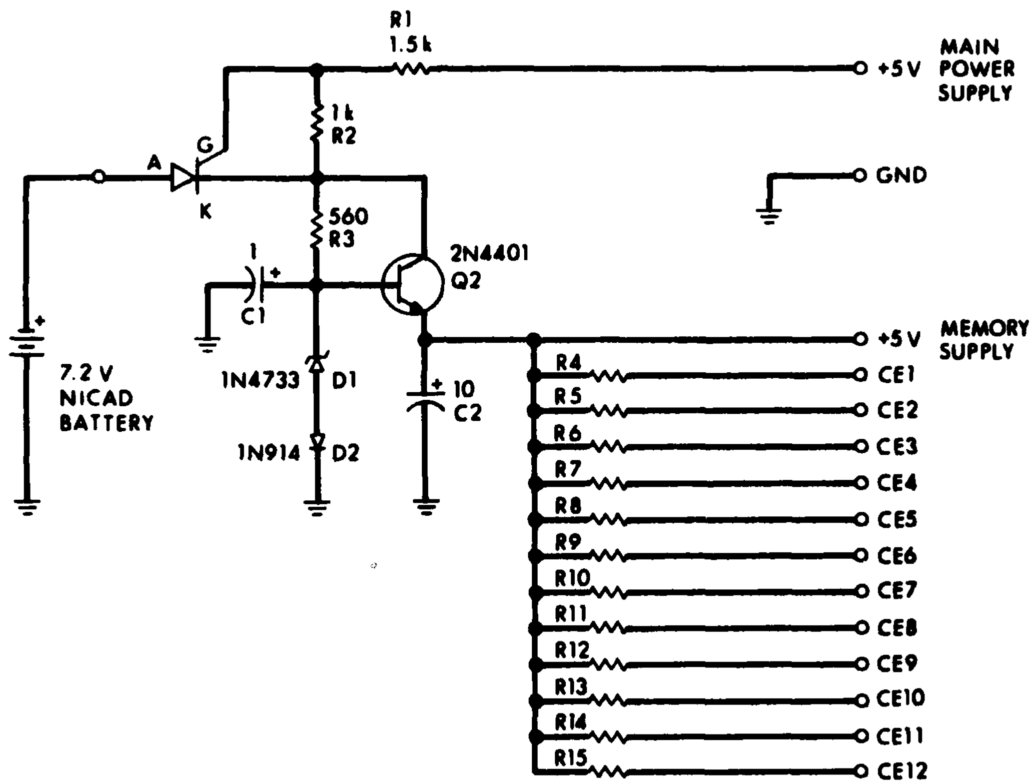

FIGURE 34
SCHEMATIC DIAGRAM OF THE MEMORY POWER SUPPLY

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chip enable signals under control of the computer to enable the computer to read the data from the memory chips.

Figure 35 is a diagram of the interface unit. An 18-conductor flat ribbon cable is connected to the input-output connector of the MPU board of the microcomputer. The interface part of the microcomputer consists of a peripheral interface adapter (PIA) chip which has two programmable 8-bit data buses and four control lines. The data buses are labeled PA0 through PA7 and PB0 through PB7 and the control lines are CA1, CB1, CA2, and CB2. The buses and control lines can be programmed by the computer as either inputs or outputs. In this case, the PA bus is programmed as inputs to read the memory data bus in the profilometer and the PB bus is programmed as outputs to generate the chip enable signals for the profilometer memory chips. Since there are not enough data lines available to also generate the address signals, a CD4040 counter controlled by the CA2 and CB2 lines is used.

Operation of the microcomputer is explained in more detail in Appendix B.

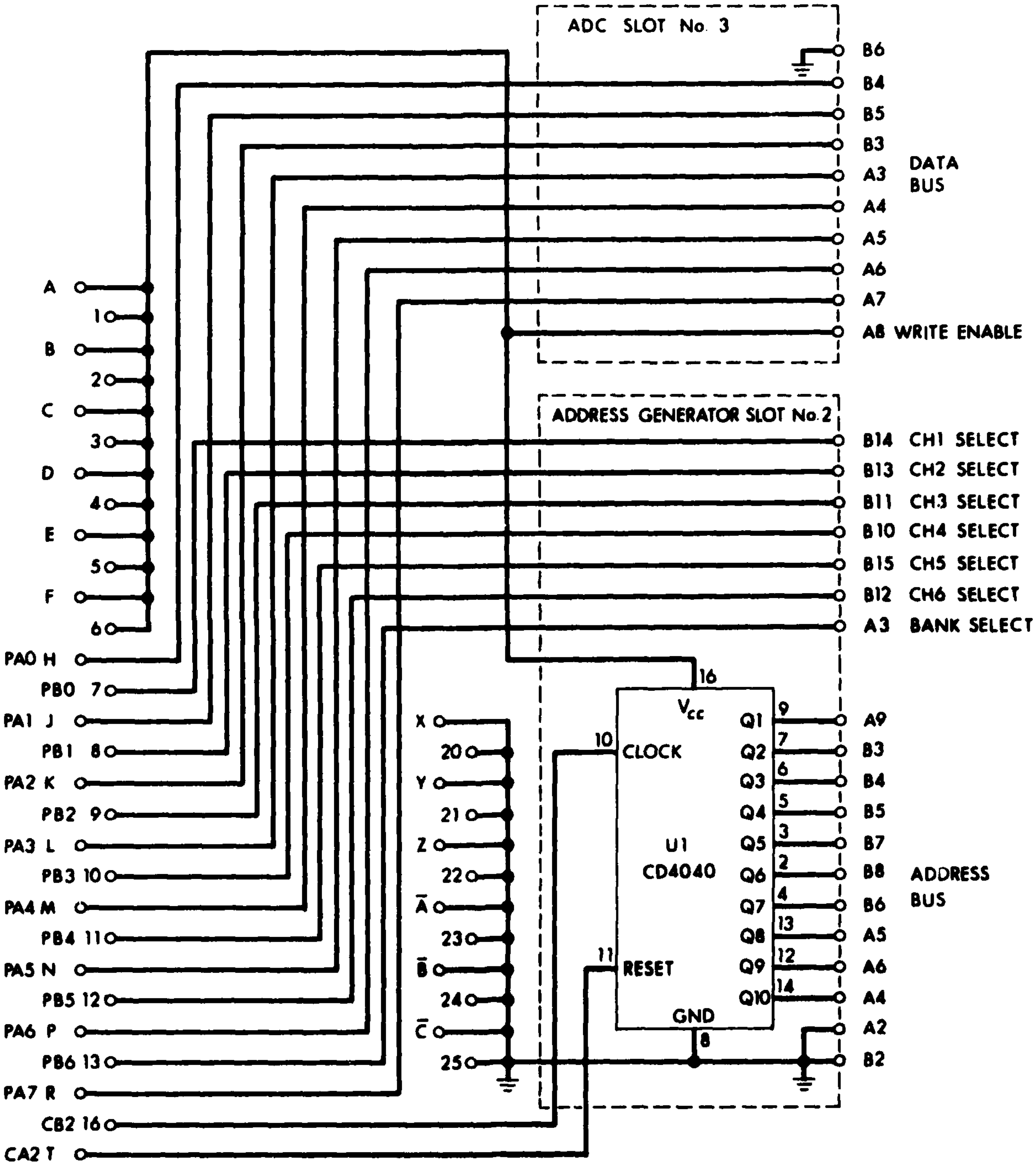

FIGURE 35
SCHEMATIC DIAGRAM OF THE MICROCOMPUTER TO MEMORY INTERFACE BOARD

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APPENDIX B

Introduction

The microcomputer unit used with the profilometer acoustical measurement system is built around a Motorola MEK6800D2 evaluation kit. The kit consists of a complete microprocessor unit (MPU) on a finished printed circuit board with a hexidecimal keyboard and associated readout. The microcomputer unit was completed by adding a power supply, a 16-kilobyte static memory board, and an input-output board. The input-output board enables the computer to digitize 8 channels of data and to provide signals to an X-Y plotter so that data stored in memory can be plotted. Only the memory board and the input-output board will be explained in detail. A detailed explanation and schematic for the MPU board can be obtained from the Motorola MEK6800D2 manual.

Figure 36 shows a photograph of the complete microcomputer unit with the top cover removed and the card cage raised to the test position.

Memory Board

Figure 37 is the schematic diagram of the microcomputer memory board which implements a 16-kilobyte static memory. U1 through U32 are type 2142 static memory chips comprising 4098 bits organized as 1024 4-bit words each. A total of 32 chips are used to implement the 16 kilobytes of memory.

The 8 data lines (D0 through D7) and the first 10 address lines (A0 through A9) from the MPU board are connected in parallel to all 32 of the memory chips to form an 8-bit data bus and a 10-bit address bus. The next 3 address lines (A10, A11, and A12) are decoded by a 3 line-to-8 line decoder, U33, to enable the selection of appropriate chips. The top 3 address lines (A13, A14, and A15) are decoded on the MPU board and provide the 2/3 and 4/5 selection signals to select

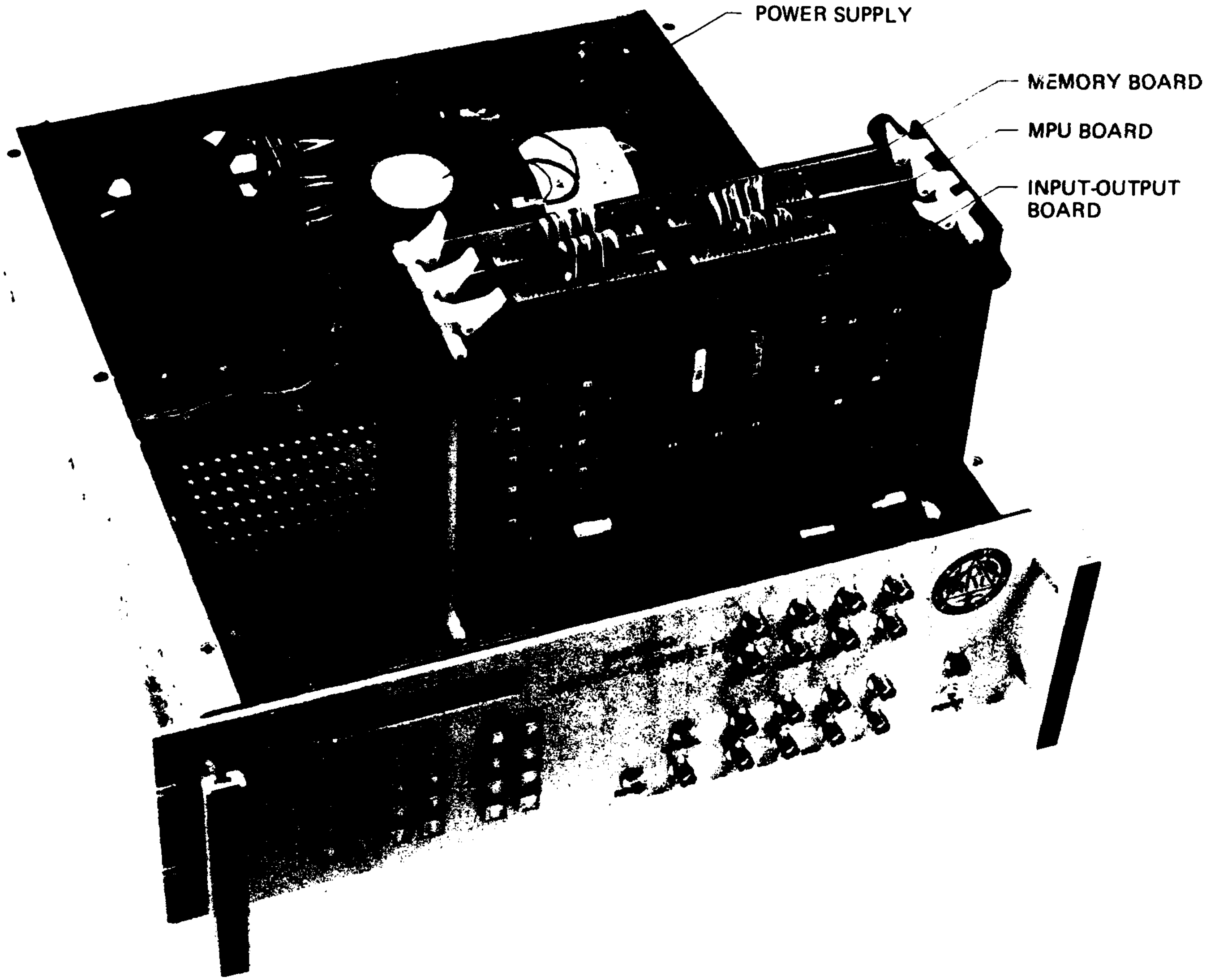

FIGURE 36
PROFILOMETER PLAYBACK MICROCOMPUTER UNIT

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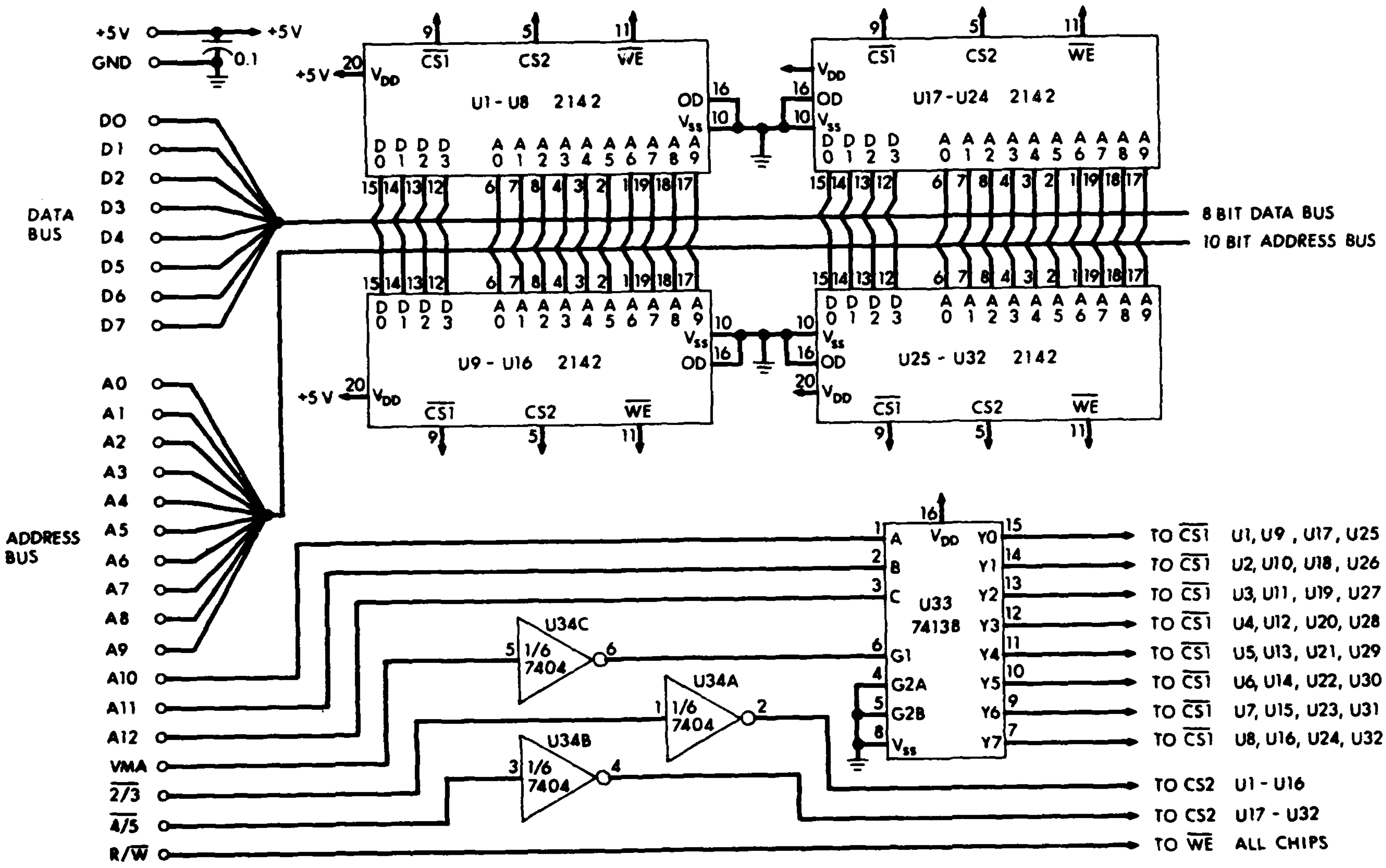

FIGURE 37
SCHEMATIC DIAGRAM OF THE MICROCOMPUTER MEMORY BOARD

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either of the two 8K pages of memory. The READ/WRITE (R/W) signal controls the writing of data into the memory chips and is connected to the WRITE ENABLE ($\overline{WE}$) inputs.

Input-Output Board

Figure 38 is the schematic diagram of the microcomputer input-output board which is used to input analog data to the microcomputer and to output analog data to an X-Y plotter from the computer.

The MPU board of the microcomputer has two 16-bit parallel interface connections implemented with MC6821 peripheral interface adapters (PIA). One of the ports is dedicated to the keyboard/display circuits and the other is available for user access. This second port is used for connection to either the interface circuit (see description in Appendix A) or to the input-output board. The port connections of the PIA can be controlled by the MPU to be either an input or an output. For use with the input-output board, 8 of the parallel lines (PA0 through PA7) are programmed to be the data port and are set up to be inputs or outputs, depending on direction of data flow. The other 8 lines (PB0 through PB7) are set up as outputs to control the various circuits on the input-output board.

U1 is an 8-input multiplexer under program control through PB5, PB6, and PB7, which select the analog input channel to be digitized. U2 is an operational amplifier which, in conjunction with C3 and the multiplexer, operates as a sample-and-hold amplifier to hold the analog signal constant during the digitization process. U3 is an 8-bit analog-to-digital converter module with an internal clock. The A/D process is started under program control through PB4. After the input signal has been digitized and the digital output of U3 is stable, the MPU is signaled through the end of conversion line (EOC) CB1 which serves as an interrupt line to the MPU. U4 and U5 serve as interface buffers with 3-state outputs to enable bus operation on the board. The data output to the data bus from the ADC is enabled under program control

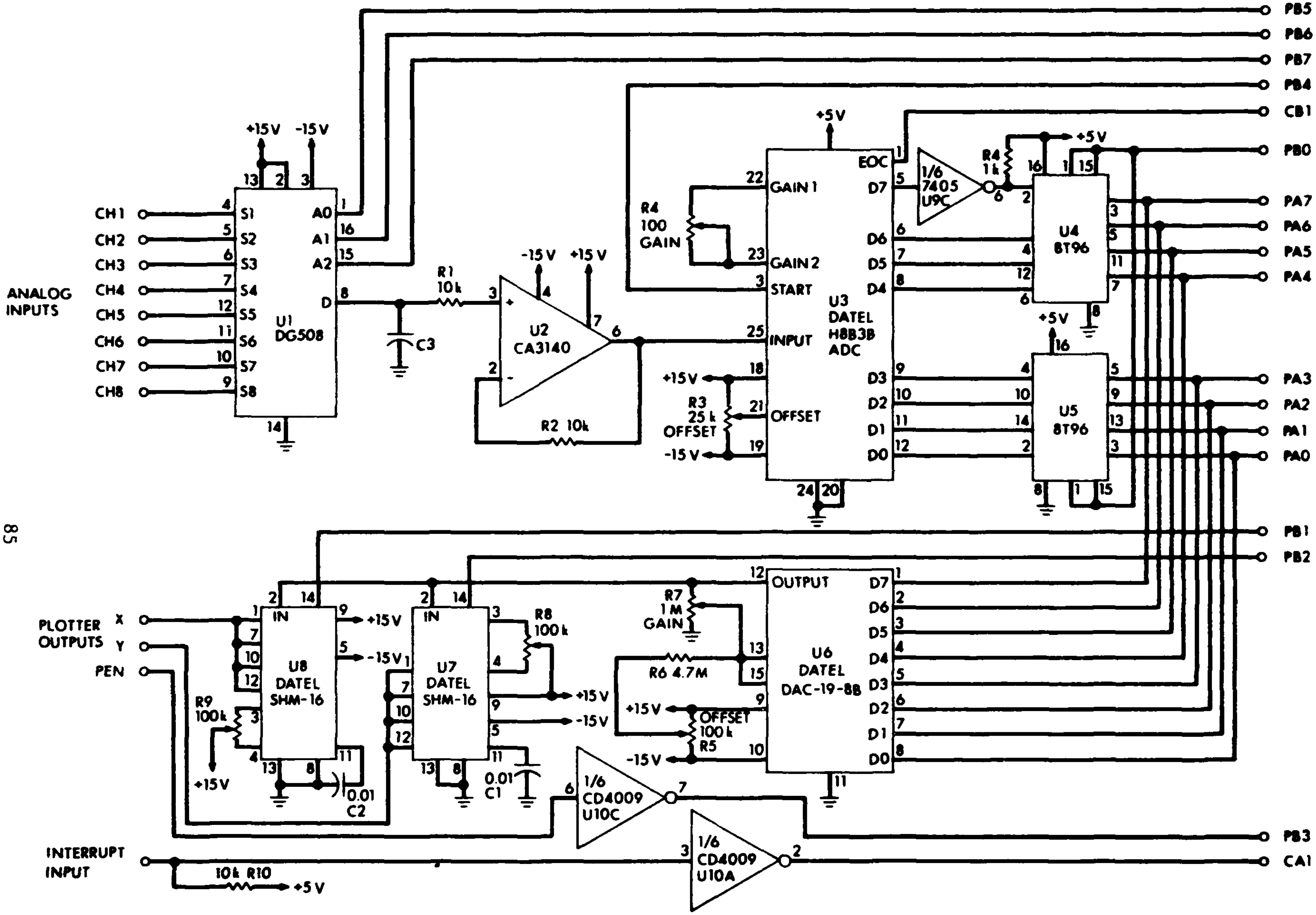

FIGURE 38
SCHEMATIC DIAGRAM OF THE MICROCOMPUTER INPUT-OUTPUT BOARD

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through PB0. U9C is an inverter for the most significant data bit (MSB) to change the straight binary output of the ADC to a 2's complement output which is compatible with arithmetic operations of the MPU.

When the board is used for an output, the data are routed to the digital-to-analog converter module U6. The sample-and-hold amplifiers are used to store the X and Y coordinates for the X-Y plotter during the pen relocation time of the plotter. The sample-and-hold amplifiers are under program control through PB1 and PB2.

There are two direct digital lines from the MPU through PB3 and CA1. The CA1 line is used as an interrupt line from a front panel switch to control the time the MPU starts digitizing data from the inputs. The PB3 signal allows the MPU to control pen up or pen down positions on the X-Y plotter.

APPENDIX C

I. Introduction

The software to enable the microcomputer to operate in the appropriate modes to digitize data, to plot data, or to extract digital data directly from the profilometer is contained on 2 ultraviolet erasable programmable read only memories (EPROM) on the MPU board. Computer printouts and flow diagrams of the programs are included in this Appendix. Section II contains instructions for setting up and running the programs.

II. Profilometer Microcomputer Unit Programs

A. Use with magnetic tape system

1. Attach BNC cable from Profilometer Playback Unit acceleration channel to input channel 1 on microprocessor front panel; from time delay channel to input 2; and from amplitude channel to input 3.
2. Connect cable from X-Y plotter output on back panel of microprocessor to plotter input.
3. OPTIONAL: To monitor X and Y outputs from microprocessor, connect BNC cables from microprocessor output channel 1 (Y) and channel 2 (X) to storage oscilloscope.
4. Turn on microprocessor. DASH prompt will appear on left side of display.
5. Enter program constants:

   (1) Enter 0000. Punch "M".

   Now enter desired x axis parameter according to the following table.

   01 - Acceleration

   02 - Time Delay

   03 - Amplitude

   04 - Velocity

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05 - Depth

06 - Time

07 - Sound Speed

(2) Punch "G". Address "0001" appears. Enter y-axis parameter as in Step 5(1).

(3) Punch "G". Enter A/D sample period (16-bit hexadecimal number greater than zero). At address "0002" enter most significant 2 digits of sample period.

(4) Punch "G". Enter least significant 2 digits of sample period. A/D sample period is found by the following formula:

Sample period = (13 μsec × N1) + 295 μsec,

where N1 is the hexadecimal number entered into 0002 and 0003. Total A/D time is given by:

A/D time = (13 μsec × N1) + 295 μsec × 2048 bytes.

Solving for N1 yields:

$$N1 = \frac{[\text{A/D time (sec)}/2048] - 295\ \mu\text{sec}}{13\ \mu\text{sec}} .$$

This gives N1 in decimal, which must be converted to hexadecimal before entering into memory.

(5) Enter D/A sample period into locations 0004 (most significant byte) and 0005 (least significant byte). D/A sample period is given by:

Sample period = 13 μsec × N2 + 255 μsec.

D/A time varies depending on whether or not the x axis represents time.

A good value for N2 is 1500.

6. Program is now ready to run.

(1) Punch escape "E".

(2) Enter "6000".

(3) Punch "G".

Program is now initialized and waiting for an interrupt to start digitizing. Just before the area of tape to be analyzed passes by the read head of the playback unit, punch MANUAL INTERRUPT on front panel. Program will stop at 603D when it is through digitizing. Memory changes made:

1. Locations 2000 - 27FF: Acceleration
2. Locations 2800 - 2FFF: Time Delay
3. Locations 3000 - 37FF: Amplitude

Acceleration is normalized by taking the average of the last 64 bytes = 0.

To check the contents of these locations.

(1) Punch ESCAPE.

(2) Enter address to be examined (2000 above, e.g.).

(3) Punch "M". Contents of that particular memory location will be displayed.

7. (1) Punch ESCAPE.

(2) Enter 603E. Punch "G". Program will now integrate acceleration to get velocity, integrate velocity to get depth, and invert time delay to get sound speed. Memory changes:

1. 3800 - 3FFF: Velocity
2. 4000 - 47FF: Depth
3. 4800 - 4FFF: Sound Speed
4. 0006 - DVCNT1: Number of times acceleration was divided by 2 to get velocity.
5. 0007 - DVCNLT2: Number of times velocity was divided by 2 to get depth.
6. 0008 - SCNT: Number of times sound speed was multiplied by 2 before plotting. Scale on the sound speed plot is found from

$$SS = (\$FFFF/td) \times 2^N \quad ,$$

where

SS - Sound Speed,

td = Time Delay, and

N = Shift Count (SCNT).

The last 3 values above (DVCNT1, DVCNT2, SCNT) should be noted on the plots. These are necessary to determine scale and will usually be different for each profile.

8. Data can be plotted now.
   (1) Punch ESCAPE.
   (2) Enter 607B. Punch "G". Program will stop at 60AA.
9. Any other parameters can be plotted now by punching ESCAPE, entering new values into location $0000 and $0001 (Steps 5(1) and 5(2) and repeating Step 8.

B. Use with solid state memory system

1. After data have been recorded in the recording unit, be sure that during retrieval of the unit from the corer that the switch cable is unplugged and that a blank cover is installed on the waterproof connector.
2. Remove recorder unit from the pressure case and place on a workbench near the microprocessor unit. Attach bench test switch cable with switch in the OFF or center position. Check that main battery voltage is at least 12 V.
3. Attach the interface cable to the IO port on the MPU board in the microprocessor unit.
4. Remove board 2 (address generator board) and board 3 (ADC board) and plug the interface into the two open slots of the profilometer unit.
5. Turn on power to the microprocessor unit and wait for "DASH" prompt signal to appear on the microprocessor readout.
6. Turn switch on profilometer recorder to P/S.
7. Enter C000 into address space of microprocessor and push the "G" button.

8. Data will then be extracted from the profilometer recorder unit and C048 will appear on readout. The following address spaces will contain the listed blocks of data:

2000-27FF	Channel 1 data
2800-2FFF	Channel 2 data
3000-37FF	Channel 3 data
3800-3FFF	Channel 4 data
4000-47FF	Channel 5 data
4800-4FFF	Empty

9. The data blocks should be stored on a magnetic tape via the MPU cassette interface to ensure that the data are not lost.

10. Next enter C07B and push "G" button. The acceleration data will be normalized (last 64 bytes averaged and the average value subtracted from all the data to ensure that the acceleration at rest is zero), then integrated twice to get depth. This process is similar to that in Section II.A. The address of DVCNT1 is 0007 and of DVCNT2 is 0008. Data are stored in memory as follows:

2000-27FF	CH 1 Acceleration
2800-2FFF	Ch 2
3000-37FF	Ch 3
3800-3FFF	Ch 4
4000-47FF	Ch 5
4800-4FFF	Velocity
5000-57FF	Depth

11. Data can now be plotted as in Section II.A except that the address of the beginning byte of data to be plotted on each coordinate must be entered directly in memory as follows:

(1) Enter 001C and push "M".

(2) Enter MSB of x axis starting data address (for example, to plot with depth as x axis the starting address would be 5000, so 50 would be entered in 001C).

(3) Push "G"; address 001D will appear in readout.

(4) Enter LSB of x axis starting data address (for above example, 00).

(5) Push "G"; address 001E will appear in readout.

(6) Enter MSB of y axis address.

(7) Push "G"; address 001F will appear in readout.

(8) Enter LSB of y axis address.

(9) If data are to be plotted with time as the x axis, enter 0000 in steps 2 and 4.

(10) Push "E" and enter C10E in address after prompt dash appears.

(11) Push "G"; data will be plotted on X-Y plotter.

MOTOROLA M68SAM CROSS-ASSMBLER

MOTOROLA M6800 CROSS ASSEMBLER, RELEASE 1.3

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*
*                   APPLIED RESEARCH LABS
*                   UNIVERSITY OF TEXAS, AUSTIN
*                   JUNE 19, 1979
*                   R. TOMPKINS
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*
*            THIS PROGRAM DIGITIZES 3 CHANNELS OF ANALOG
*            DATA. INPUT CONNECTIONS ARE:
*                  CH. 1 = ACCELERATION
*                  CH. 2 = TIME DELAY
*                  CH. 3 = AMPLITUDE
*            AFTER DIGITIZING, TIME DELAY DATA ARE
*            INVERTED, YIELDING SOUND SPEED, AND
*            ACCELERATION IS INTEGRATED TO YIELD
*            VELOCITY AND DEPTH.  ANY ONE PARAMETER
*            MAY THEN BE PLOTTED AS A FUNCTION OF
*            ANY OTHER OR OF TIME.
*            PARAMETERS TO BE PLOTTED ON THE X AND
*            Y AXES ARE SELECTED BY ENTERING ONE OF
*            THE FOLLOWING ASSIGNMENTS INTO
*            LOCATIONS ≠XSEL≠ AND ≠YSEL≠.
*                  01. ACCELERATION
*                  02. TIME DELAY
*                  03. AMPLITUDE
*                  04. VELOCITY
*                  05. DEPTH
*                  06. TIME
*                  07. SOUND SPEED
*
*            THE FOLLOWING CONSTANTS MUST BE ENTERED
*            INTO MEMORY BEFORE PROGRAM EXECUTION:
*            1. ENTER DESIRED X OUTPUT PARAMETER INTO
*               XSEL, LOCATION $0000.
*            2. ENTER DESIRED Y OUTPUT PARAMETER INTO
*               YSEL, $0001.
*            3. ENTER 2 BYTE INPUT LOOP DELAY LENGTH.
*               MOST SIGNIF. BYTE INTO INDEL, $0002.
*               LEAST SIGNIF. INTO $0003.
*            4. ENTER 2 BYTE OUTPUT LOOP DELAY LENGTH.
*               MS BYTE INTO OUTDEL,$0004. LS BYTE
*               INTO $0005
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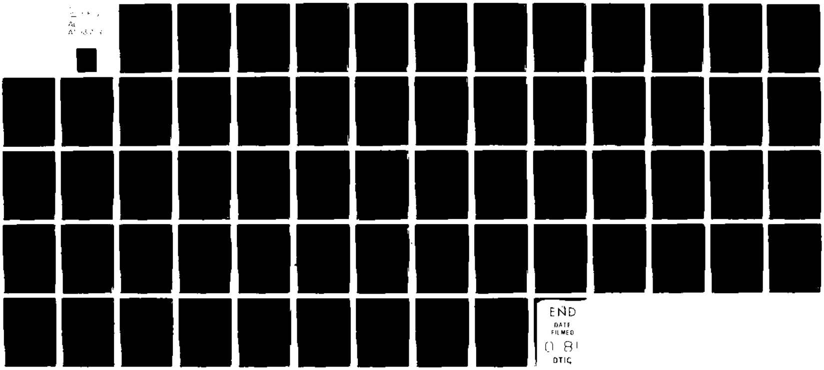


```
                    *
                    *
                    *                                  LABEL ASSIGNMENTS FOLLOW:
          E0E0      DELAY   EQU     $E0E0
          2000      ACCBLK  EQU     $2000     DATA BUFFERS
          2800      TDBLK   EQU     $2800
          3000      AMPBLK  EQU     $3000
          3800      VELBLK  EQU     $3800
          4000      DEPBLK  EQU     $4000
          4800      SSBLK   EQU     $4800
          5000      SCR16   EQU     $5000
          0000      TIME    EQU     $0000
          6000      FIN     EQU     $6000     END
                    *
     0000                   ORG     $0000
     0000 0001      XSEL    RMB     1         X-AXIS PARAMETER
     0001 0001      YSEL    RMB     1         Y-AXIS PARAMETER
     0002 0002      INDEL   RMB     2         A/D DELAY
     0004 0002      OUTDEL  RMB     2         D/A DELAY
     0006 0001      DVCNT1  RMB     1         FIRST INTEGRATION DIV.
     0007 0001      DVCNT2  RMB     1         2ND INTEGRATION DIV. COUNT
     0008 0001      DIVCNT  RMB     1         SCRATCH DIVISION COUNT
          0008      SCNT    EQU     $0008
     0009 0002      ACCIX   RMB     2         BUFFER POINTERS
     000B 0002      TDIX    RMB     2
     000D 0002      AMPIX   RMB     2
     000F 0002      VELIX   RMB     2
     0011 0002      DEPIX   RMB     2
     0013 0002      SSIX    RMB     2
     0015 0002      IX16    RMB     2
     0017 0002      IX2     RMB     2
     0019 0001      AVGMSB  RMB     1
     001A 0001      AVGLSB  RMB     1
```

```
00087 001B 0001      XTOUT  RMB      1
00088 001C 0002      XSCRCH RMB      2
00089 001E 0002      YSCRCH RMB      2
00090 0020 0002      IX3    RMB      2
 RT1              MOTOROLA M68SAM CROSS-ASSMBLER


00091 0022 0001      NEGFLG RMB      1
00092 0023 0001      XKDVSH RMB      1
00093 0024 0002      XKDVND RMB      2
00094 0026 0002      XKOUOT RMB      2
00095 0028 0001      XKDSPL RMB      1
00096 0029 0001      INITX  RMB      1
00097 002A 0001      INITY  RMB      1
00098 002B 0002      BIGGST RMB      2
00099      8004      PRA    EQU      $8004    PERIPH. REG. A (PIA)
00100      8004      DDRA   EQU      $8004    DATA DIRECTION REG A
00101      8005      CRA    EQU      $8005    CONTROL REG A
00102      8006      PRB    EQU      $8006    PERIPH. REG. B
00103      8006      DDRB   EQU      $8006    DATA DIRECTION REG B
00104      8007      CRB    EQU      $8007    CONTROL REG. B
00105                *********************************************
 RT1              MOTOROLA M68SAM CROSS-ASSMBLER
```

```
6000                       ORG    $6000
                    *
                    *
6000 BD 60AB               JSR    INSET      SET PIA INPUTS.
6003 BD 60E4               JSR    CLRMEM     CLEAR DATA MEMORY.
6006 CE 601A               LDX    #INTVEC
6009 FF A000               STX    $A000
600C 7F 0006               CLR    DVCNT1
600F 7F 0007               CLR    DVCNT2
6012 7F 0017               CLR    IX2        CLEAR PSEUDO-IX.
6015 7F 0018               CLR    IX2+1
6018 0E                    CLI
6019 3E                    WAI
                    *
601A BD 60F1  INTVEC JSR    A2D1       LOOP TO DIGITIZE.
601D BD 6106               JSR    A2D2
6020 BD 6118               JSR    A2D3
6023 DE 17                 LDX    IX2
6025 08                    INX
6026 DF 17                 STX    IX2
6028 8C 0800               CPX    #$0800     THRU DIGITIZING.
602B 2C 07                 BGE    A2DEND
602D DE 02                 LDX    INDEL
602F BD E0E0               JSR    DELAY
6032 20 E6                 BRA    INTVEC
                    *
6034 BD 6130  A2DEND JSR    AVG
6037 BD 6158               JSR    NORM
603A 7F 0008               CLR    DIVCNT
603D 3F                    SWI
                    *
```

```
                        *********   *******   *********   ********
                        *
603E CE 2000  MAIN1  LDX    =ACCBLK
6041 BD 6167         JSR    MOV16     COPY ACC. DATA INTO
                        *                        WORK AREA.

6044 BD 6199         JSR    INTGR1    INTEGRATE ONCE.
6047 5D              TST B            CHECK FOR OVERFLOW
6048 27 09           BEQ    MAIN2
604A 7C 0006         INC    DVCNT1    DIVCNT1 = NUMBER OF TIMES
                        *                        ACCELFRATION HAS BEEN
604D 96 06           LDA A  DVCNT1    DIVIDED BY 2 WHILE
                        *                        GETTING VELOCITY.
604F 97 08           STA A  DIVCNT    DIVCNT = SCRATCH.
6051 20 FB           BRA    MAIN1
                        *
6053 CE 3800  MAIN2  LDX    =VELBLK
6056 BD 618F         JSR    MOV16B    MOVE INTEGRATED ACC. DATA
                        *                        TO VELOCITY BLOCK.
                        *
6059 CE 3800  MAIN3  LDX    =VELBLK    MOVE VELOCITY TO
605C BD 6167         JSR    MOV16     WORK AREA.
                        *
605F BD 6199         JSR    INTGR1
6062 5D              TST B            OVERFLOW CHECK
6063 27 09           BEQ    MAIN4
6065 7C 0007         INC    DVCNT2    NO. OF TIMES VEL. WAS
6068 96 07           LDA A  DVCNT2    DIVIDED BY 2 WHILE
606A 97 08           STA A  DIVCNT    GETTING DEPTH.
606C 20 FB           BRA    MAIN3
606E BD 638F  MAIN4  JSR    FUDGE     MODIFY RESULTS OF
                        *                          2ND INTEGRATION.
6071 CE 4000  MAIN5  LDX    =DEPBLK    MOVE INTEGRATED VEL.
```

```
6074 BD 61BF          JSR    MOV16B   INTO DEPTH.
                *
                *
                *
6077 BD 630C MAIN6    JSR    INVERT   INVERT TIME DELAY TO
RTI              MOTOROLA M68SAM CROSS-ASSMBLER



                *                             GET SOUND SPEED.
607A 3F               SWI
                *
                *
                ******   *********   ************   *******A
                *
                *                             NOW OUTPUT DATA.

                *
607B BD 610B          JSR    OUTSET   SET PIA OUTPUTS.
607E 96 00            LDA A  XSEL     INZ OUTPUT POINTERS.
6080 BD 62A0          JSR    SELBLK
6083 DF 1C            STX    XSCRCH
6085 96 01            LDA A  YSEL
6087 BD 62A0          JSR    SELBLK
608A DF 1E            STX    YSCRCH
608C BD 6285          JSR    PNSTRT   INZ PEN POSITION.
608F CE 0000          LDX    #0000
6092 DF 17   OUTDTA   STX    IX2
6094 BD 61F8          JSR    OUTX     OUTPUT 1 X VALUE.
6097 BD 6220          JSR    OUTY     OUTPUT 1 Y VALUE.
609A DE 04            LDX    OUTDEL
609C BD E0E0          JSR    DELAY
609F DE 17            LDX    IX2
60A1 08               INX
60A2 8C 0800          CPX    #$0800   THRU PLOTTING?
60A5 2D EB            BLT    OUTDTA
60A7 BD 6269          JSR    PENUP
```

```
60AA 3F                  SWI
                    *
                    *
                    ***************************************************
                    *             ***SUBROUTINE TO SET PIA INPUTS,
                    *              AND INITIALIZE BUFFER POINTERS
                    *
60AB 7F 8006 INSET  CLR      DDRB
60AE 7F 8007        CLR      CRB
60B1 86 FF          LDA A    #$FF
 RTI           MOTOROLA M68SAM CROSS-ASSMBLER


60B3 B7 8006        STA A    DDRB
60B6 86 14          LDA A    #$14
60B8 B7 8007        STA A    CRB
60BB 7F 8005        CLR      CRA
60BE 7F 8004        CLR      DDRA
60C1 4C             INC A
60C2 B7 8005        STA A    CRA
60C5 CE 2000        LDX      #ACCBLK
60C8 DF 09          STX      ACCIX
60CA CE 2800        LDX      #IDBLK
60CD DF 0B          STX      IDIX
60CF CE 3000        LDX      #AMPBLK
60D2 DF 0D          STX      AMPIX
60D4 CE 3800        LDX      #VELBLK
60D7 DF 0F          STX      VELIX
60D9 CE 4000        LDX      #DEPBLK
60DC DF 11          STX      DEPIX
60DE CE 4800        LDX      #SSBLK
60E1 DF 13          STX      SSIX
60E3 39             RTS
                    *
```

```
                             *
                             *
 RT1                  MOTOROLA M68SAM CROSS-ASSMBLER
```

```
                             ****************************************************
                             *          SUBROUTINE TO CLEAR ALL OF DATA MEMORY
      60F4 CE 2000 CLRMEM  LDX      =ACCBLK
      60F7 4F              CLR A
      60F8 A7 00   ZLOOP   STA A    0,X
      60FA 08              INX
      60FB 8C 6000         CPX      =FIN
      60FE 2D F8           BLT      ZLOOP
      60F0 39              RTS
                             *
                             *
                             *
                             ****************************************************
                             *                **SUBROUTINE TO GET ONE ACC. DATUM.**
      60F1 DE 09   A2D1    LDX      ACCIX
      60F3 86 1E           LDA A    =$1E
      60F5 B7 8006         STA A    PRB
      60F8 86 06           LDA A    =$06
      60FA B7 8006         STA A    PRB
      60FD B6 8004         LDA A    PRA
      6100 A7 00           STA A    0,X
      6102 08              INX
      6103 DF 09           STX      ACCIX
      6105 39              RTS
                             *
```

```
                          *
RT1               MOTOROLA M68SAM CROSS-ASSMBLER

                          ******************************************************
                          *                **SUBROUTINE TO GET ONE TIME DELAY DATUM.*
                          *                **IX RETURNS INCREMENTED.**
      6106 DE 0B          A2D2   LDX      TDIX
      6108 86 3E                 LDA  A   =$3E
      610A B7 8006               STA  A   PRB
      610D 86 26                 LDA  A   =$26
      610F B7 8006               STA  A   PRB
      6112 B6 8004               LDA  A   PRA
      6115 A7 00                 STA  A   0,X
      6117 08                    INX
      6118 DF 0B                 STX      TDIX
      611A 39                    RTS
                          *
                          *
                          ******************************************************
                          *                **SUBROUTINE TO GET ONE AMPLITUDE DATUM.**
                          *                **IX RETURNS INCREMENTED.**
      611B DE 0D          A2D3   LDX      AMPIX
      611D 86 5E                 LDA  A   =$5E
      611F B7 8006               STA  A   PRB
      6122 86 46                 LDA  A   =$46
      6124 B7 8006               STA  A   PRB
      6127 B6 8004               LDA  A   PRA
      612A A7 00                 STA  A   0,X
      612C 08                    INX
      612D DF 0D                 STX      AMPIX
      612F 39                    RTS
                          *
```

```
00293                    *
00294                    *
 RT1             MOTOROLA M68SAM CROSS-ASSMBLER


00296                    **************************************************
00297                    *                   **SUBROUTINE TO FIND AVG. OF LAST 64
00298                    *                   **ACCELERATION VALUES.  RESULT IS

00299                    *                   **RETURNED IN B REG.
00300 6130 7F 001A AVG      CLR      AVGLSB
00301 6133 7F 0019          CLR      AVGMSB
00302 6136 CE 2800          LDX      =IDBLK
00303 6139 C6 40            LDA B    =64
00304 613B 09      AVGLP1   DEX
00305 613C A6 00            LDA A    0,X
00306 613E 9B 1A            ADD A    AVGLSB
00307 6140 97 1A            STA A    AVGLSB
00308 6142 24 03            BCC      DECNTR
00309 6144 7C 0019          INC      AVGMSB
00310 6147 5A      DECNTR   DEC B
00311 6148 26 F1            BNE      AVGLP1
00312                    *                   *****NOW SHIFT RIGHT 6 PLACES.***
00313 614A C6 06            LDA B    =06
00314 614C 74 0019 AVGLP2   LSR      AVGMSB
00315 614F 76 001A          ROR      AVGLSB
00316 6152 5A               DEC B
00317 6153 26 F7            BNE      AVGLP2
00318 6155 D6 1A            LDA B    AVGLSB
00319 6157 39               RTS
```

```
                         *
                         *

 RT1               MOTOROLA M68SAM CROSS-ASSMBLER

                         *
                         ***********************************************************
                         *                     ***SUBROUTINE TO NORMALIZE ACC. DATA.**
                         *                     ***ENTRY: B REG. CONTAINS RESULT OF
                         *                     ***AVG. SUBROUTINE.
 6158 CE 2000  NORM      LDX      =ACCBLK
 615B A6 00    NORM1     LDA A    0,X
 615D 10                 SBA
 615E A7 00              STA A    0,X
 6160 08                 INX
 6161 8C 2800            CPX      =IDBLK
 6164 2D F5              BLT      NORM1
 6166 39                 RTS
                         *
                         *
                         *
                         ***********************************************************
                         *                     **SUBROUTINE TO MOVE ANY 2K BYTES
                         *                     **OF 8 BIT WORDS INTO AN AREA OF
                         *                     **4K 16 BIT WORDS CALLED SCR16.
                         *                     **STARTING ADDRESS OF 8 BIT BLOCK
                         *                     **IS PASSED IN IX.  MSB IS
                         *                     **STORED FIRST.
 6167 DF 17    MOV16     STX      IX2
 6169 CE 5000            LDX      =SCR16
 616C DF 15              STX      IX16
 616E DE 17    M1        LDX      IX2
 6170 A6 00              LDA A    0,X
                         *                     **NOW TEST DIVCNT. IF DIVCNT NOT
                         *                     **EQUAL TO 0. A PREVIOUS OPERATION
                         *                     **ON THE 16 BIT DATA HAS OVERFLOWED.
                         *                     **NOW THE 16 BIT BLOCK IS RELOADED
                         *                     **AND EACH VALUE IS SHIFTED RIGHT THE
                         *                     **NO. OF PLACES IN DIVCNT.
```

```
00357 6172 7D 0008          TST    DIVCNT
00358 6175 27 06            BEQ    M3
00359 6177 D6 08            LDA B  DIVCNT
 RT1              MOTOROLA M68SAM CROSS-ASSMBLER


00360 6179 47         M2    ASR A
00361 617A 5A               DEC B
00362 617B 26 FC            BNE    M2
00363 617D 48         M3    ASL A               CHECK SIGN.
00364 617E 24 04            BCC    M4
00365 6180 C6 FF            LDA B  #$FF         B=SIGN EXTENSION.
00366 6182 20 01            BRA    M5
00367 6184 5F         M4    CLR B
00368 6185 46         M5    ROR A
00369 6186 08               INX
00370 6187 DF 17            STX    IX2
00371 6189 DE 15            LDX    IX16
00372 618B E7 00            STA B  0,X
00373 618D 08               INX
00374 618E A7 00            STA A  0,X
00375 6190 08               INX
00376 6191 DF 15            STX    IX16
00377 6193 8C 6000          CPX    #FIN
00378 6196 2D D6            BLT    M1
00379 6198 39               RTS
00380                 *
00381                 *
00382                 *
 RT1              MOTOROLA M68SAM CROSS-ASSMBLER          PAGE 14
```

```
                   ***********************************************
                   *                    **THIS SUBROUTINE INTEGRATES THRU
                   *                    **THE 16 RTI DATA BLOCK BACKWARDS.
                   *                    **OVERFLOW IS INDICATED BY RETURNING
                   *                    **$FF IN B REG.
6199 CE 6000 INTGRT LDX    =FIN
619C DF 15          STX    IX16
619E 09             DEX
619F 09             DEX
61A0 09             DEX
61A1 09             DEX
61A2 5F             CLR B
61A3 A6 03   I1     LDA A  3,X
61A5 AB 01          ADD A  1,X      ADD L.S. BYTES
61A7 A7 01          STA A  1,X
61A9 A6 02          LDA A  2,X
61AB A9 00          ADC A  0,X      ADD MS BYTES.
61AD 28 04          BVC    I2       OVERFLOW?
61AF C6 FF          LDA B  =$FF
61B1 20 0B          BRA    I3
61B3 A7 00   I2     STA A  0,X
61B5 09             DEX
61B6 09             DEX
61B7 DF 15          STX    IX16
61B9 8C 5000        CPX    =SCR16
61BC 2C F5          BGE    I1
61BE 39      I3     RTS
                   *
                   *
                   *
RTI             MOTOROLA M68SAM CROSS-ASSEMBLER
```

```
00415                   *************************************************
00416                   *                    **SUBROUTINE TO MOVE MOST SIGNIF.
00417                   *                    **BYTES FROM 16 BIT DATA BLOCK
00418                   *                    **TO 8 BIT WORD DATA BLOCK
00419                   *                    **WITH STARTING ADDRESS PASSED
00420                   *                    **IN IX.
00421 61BF DF 17   MOV16M STX    IX2
00422 61C1 CE 5000        LDX    #SCR16
00423 61C4 DF 15          STX    IX16
00424                   *
00425 61C6 A6 00   MB1    LDA A  0,X
00426 61C8 08             INX
00427 61C9 08             INX
00428 61CA DF 15          STX    IX16
00429 61CC DE 17          LDX    IX2
00430 61CE A7 00          STA A  0,X
00431 61D0 08             INX
00432 61D1 DF 17          STX    IX2
00433 61D3 DE 15          LDX    IX16
00434 61D5 8C 6000        CPX    #FIN
00435 61D8 2D EC          BLT    MB1
00436 61DA 39             RTS
00437                   *
00438                   *
00439                   *
 RTI             MOTOROLA M68SAM CROSS-ASSMBLER
```

```
                       ************************************************
                       *               **SUBROUTINE TO SET PIA OUTPUTS.
61DB 7F 8005 OUTSET   CLR    CRA
61DE 7F 8007          CLR    CRB
61E1 86 FF            LDA A  =$FF
61E3 B7 8004          STA A  DDRA
61E6 B7 8006          STA A  DDRB
61E9 86 17            LDA A  =$17
61EB B7 8005          STA A  CRA
61EE 86 14            LDA A  =$14
61F0 B7 8007          STA A  CRB
61F3 86 80            LDA A  =$80
61F5 97 1B            STA A  X1OUT     INITIAL TIME VALUE.
61F7 39               RTS

                       *
                       *
                       *
                       ************************************************
                       *               **SUBROUTINE TO OUTPUT 1 BYTE
                       *               **FROM REG. A TO X-AXIS WITH
                       *               **PEN DOWN.
61F8 96 1C   OUTX     LDA A  XSCRCH
61FA 27 09            BEQ    OUT1
61FC DE 1C            LDX    XSCRCH
61FE A6 00            LDA A  0,X
6200 08               INX
6201 DF 1C            STX    XSCRCH
6203 20 05            BRA    OUT1X
6205 96 1B   OUT1     LDA A  X1OUT
6207 7C 001B          INC    X1OUT
                       *               NOW OUTPUT ONE BYTE FROM REG. A
                       *               TO X-AXIS WITH PEN DOWN.
```

```
620A B7 8004 OUTIX   STA A   PRA
620D 86 0B           LDA A   #$0B
620F B7 8006         STA A   PRB
6212 63 00           COM     0,X       THESE 4 COMPLEMENTS
6214 63 00           COM     0,X       KILL 7 CYCLES EACH
RT1              MOTOROLA M68SAM CROSS-ASSEMBLER


6216 63 00           COM     0,X       WHILE D TO A CONV.
6218 63 00           COM     0,X       AND S-H SETTLE.
621A 86 0F           LDA A   #$0F
621C B7 8006         STA A   PRB
621F 39              RTS
               *
               *
               *
               *
               ***********************************************
               *
               *             **SUBROUTINE TO OUTPUT 1 BYTE
               *             **FROM REG. A TO Y-AXIS.
               *
6220 DE 1E     OUTY  LDX     YSCRCH
6222 A6 00           LDA A   0,X

6224 D6 1C           LDA B   XSCRCH    X AXIS = TIME.
6226 26 16           BNE     OUTY3
6228 C6 08           LDA B   #08       THIS IS TO ADD 8
622A DB 18           ADD B   IX2+1     TO THE IX2 INDEX
622C D7 18           STA B   IX2+1     IF X=TIME.
622F 24 03           BCC     OUTY2
6230 7C 0017         INC     IX2
6233 C6 08     OUTY2 LDA B   #08
6235 DB 1F           ADD B   YSCRCH+1   LIKEWISE WITH
6237 D7 1F           STA B   YSCRCH+1   Y INDEX.
6239 24 03           BCC     OUTY3
```

```
00505 623B 7C 001F          INC     YSCRCH
00506                 *
00507 623E DF 1E    OUTY3   LDX     YSCRCH
00508 6240 08               INX
00509 6241 DF 1E            STX     YSCRCH
00510                 *                OUTPUT 1 BYTE FROM REG.A
00511                 *                TO Y AXIS.PEN DOWN.
00512 6243 B7 8004  OUT1Y   STA A   PRA
00513 6246 86 0D            LDA A   =$0D
00514 6248 B7 8006          STA A   PRB
 RT1               MOTOROLA M68SAM CROSS-ASSMBLER


00515 624B 63 00            COM     0,X        WAITING HERE FOR
00516 624D 63 00            COM     0,X        D TO A AND S-H
00517 624F 63 00            COM     0,X        TO SETTLE.
00518 6251 63 00            COM     0,X
00519 6253 86 0F            LDA A   =$0F
00520 6255 B7 8006          STA A   PRB
00521 6258 39               RTS
00522                 *
00523                 *
00524                 *
```

```
                         *****************************************
                         *                       **SUBROUTINE TO OUTPUT REG. A
                         *                       **TO X-AXIS, PEN UP.
6259 B7 8004 OUT1XU STA A   PRA
625C 86 03          LDA A   =03
625E B7 8006        STA A   PRB
6261 63 00          COM     0,X       TIME KILLING HERE.
6263 63 00          COM     0,X
6265 63 00          COM     0,X
6267 63 00          COM     0,X
6269 86 07   PENUP  LDA A   =07       HERE TO LIFT PEN.
626B B7 8006        STA A   PRB
626E 39             RTS
                         *
                         *
                         *****************************************
                         *                       **SUBROUTINE TO OUTPUT REG. A
                         *                       **TO Y-AXIS, PEN UP.
626F B7 8004 OUT1YU STA A   PRA
6272 86 05          LDA A   =05
6274 B7 8006        STA A   PRB
6277 63 00          COM     0,X       KILLING TIME...
6279 63 00          COM     0,X
627B 63 00          COM     0,X
627D 63 00          COM     0,X
627F 86 07          LDA A   =07
6281 B7 8006        STA A   PRB
6284 39             RTS
                         *
                         *
                         *****************************************
                         *                       **SUBROUTINE TO INITTIALIZE PEN
```

```
00558                      *                        **POSITION.
00559 62A5 96 1C      PNSTRT  LDA A    XSCRCH
00560 62A7 26 04              BNE      P1
00561 62A9 86 80              LDA A    =$80
00562 62AB 20 04              BRA      P2
```

RT1 MOTOROLA M68SAM CROSS-ASSMBLER

```
00563 62AD DE 1C      P1      LDX      XSCRCH
00564 62AF A6 00              LDA A    0,X
00565 62B1 8D C6      P2      BSR      OUT1XU
00566 62B3 DE 1E              LDX      YSCRCH
00567 62B5 A6 00              LDA A    0,X
00568 62B7 8D D6              BSR      OUT1YU
00569 62B9 CE FFFF            LDX      =$FFFF
00570 62BC BD FUEU            JSR      DELAY
00571 62BF 39                 RTS
```

```
                      *
                      *
                      *******************************************************
                      *                    **SUBROUTINE TO INITIALIZE INDEX
                      *                    **DEPENDING ON DESIRED OUTPUT
                      *                    **BLOCK. REG.A CONTAINS EITHER
                      *                    **XSEL OR YSEL.
62A0 CE 62A9  SELBLK  LDX     =LDTBL-2
62A3 08       S1      INX
62A4 08               INX
62A5 4A               DEC A
62A6 26 FB            BNE     S1
62A8 EE 00            LDX     0,X
62AA 39               RTS
62AB 2000     LDTBL   FDB     $2000
62AD 2800             FDB     $2800
62AF 3000             FDB     $3000
62B1 3800             FDB     $3800
62B3 4000             FDB     $4000
62B5 0000             FDB     0000
62B7 4800             FDB     $4800
                      *
                      *
                      *******************************************************
                      *
                      *       SUBROUTINE TO DIVIDE AN UNSIGNED 4 DIGIT
                      *       HEX NUMBER (16 BIT BINARY) BY AN UNSIGNED
                      *       2 DIGIT HEX NUMBER (8 BIT BINARY).
                      *       THE DIVISOR AND THE DIVIDEND MUST BE
                      *       LOADED INTO XKDVSR AND XKDVND,XKDVND+1
                      *       RESPECTIVELY.  THEN JSR TO XKDIVD.
                      *       THE REMAINDER WILL BE IN XKDVND,
                      *       SHIFTED LEFT THE = OF BITS INDICATED IN
                      *       XKDSPL.  THE DIVISOR WILL BE
                      *       BINARILY LEFT JUSTIFIED.
                      *
```

```
00609 62B9 C6 08    XKDIVD LDA B   =08        INIT*L S=8.
00610 62BB 7F 0026         CLR     XKQUOT     ZERO QUOTIENT BUFFER
00611 62BE 7F 0027         CLR     XKQUOT+1
```



```
00612 62C1 5C       DVDLP0 INC B
00613 62C2 C1 10           CMP B   =16
00614 62C4 2E 34           BGT     DVDERR     IF S>16.DIVIDE ERROR.
00615 62C6 78 0023         ASL     XKDVSR     IF S<16 LEFT SHIFT DIVISOR.
00616 62C9 24 F6           BCC     DVDLP0     IF C=0.CONT.LOOP
00617 62CB D7 28           STA B   XKDSPL     IF C=1 XKDSPL = SHIFT CNT.
00618 62CD 76 0023         ROR     XKDVSR     SHIFT DIVISOR BACK 1 SHIFT
00619               *                                COUNT NOW IN ACCB.
00620               *                                DIVISOR LEFT JUST. IN X
00621 62D0 96 24           LDA A   XKDVND
00622 62D2 91 23    DVDLP1 CMP A   XKDVSR     IF DIVIDEND < DIVISOR
00623 62D4 25 0D           BCS     DVNSUB     DON*T SUBTRACT.
00624 62D6 0D       DVDLP2 SEC                IF THE DIVIDEND >OR= DIVISOR
00625 62D7 79 0027         ROL     XKQUOT+1     SHIFT LEFT 1 BIT.
00626 62DA 79 0026         ROL     XKQUOT     WITH LSB = 1.
00627 62DD 90 23           SUB A   XKDVSR     Y(M)=Y(M)-X
00628 62DF 97 24           STA A   XKDVND
00629 62E1 20 07           BRA     DVSHFT
00630 62E3 0C       DVNSUB CLC                SHIFT Q LEFT WITH
00631 62E4 79 0027         ROL     XKQUOT+1     LSB=0
00632 62E7 79 0026         ROL     XKQUOT
00633 62EA 5A       DVSHFT DEC B              S= S-1
00634 62EB 27 12           BEQ     DVDEND     IF S=0 STOP
00635 62ED 0C              CLC                IF S>0 SHIFT DIVIDEND
00636 62EE 79 0025         ROL     XKDVND+1     LEFT 1 BIT.LSB=0.
00637 62F1 79 0024         ROL     XKDVND     MSB INTO CARRY.
00638 62F4 96 24           LDA A   XKDVND
```

```
62F6 25 DE           BCS     DVDLP2    IF C=1 GO TO LOOP2.
62F8 20 D8           BRA     DVDLP1
62FA CE FFFF DVDERR  LDX     =$FFFF
62FD DF 26           STX     XKQUOT
62FF D6 28   DVDEND  LDA B   XKDSPL    GET SHIFT CNT INTO
6301 C0 09           SUB B   =9        ACCB. XKDSPL=XKDSPL-9.
6303 C1 04           CMP B   =4        XKDSPL < 4?
6305 25 02           BCS     DVDLP3    YES...RETURN
6307 C0 04           SUB B   =4        NO..XKDSPL=XKDSPL-4

6309 D7 28   DVDLP3  STA B   XKDSPL    DISPLACEMENT OF
RT1             MOTOROLA M68SAM CROSS-ASSMBLER


             *                   REMAINDER STORED IN XKDSPL.
630B 39              RTS
             *
             *
             *
             *
             *
             *
             ********************************************
             *         SUBROUTINE TO INVERT ENTIRE TIME
             *         DELAY DATA BLOCK AND PUT IT IN
             *         SOUND SPEED BLOCK (SSBLK). LEAVING
             *         TIME DELAY DATA INTACT.
             *
630C CE 2800 INVERT  LDX     =TDBLK
630F DF 0B           STX     TDIX
6311 CE 5000         LDX     =SCR16
             *                   ADDING =$80 MAKES ALL VALUES
             *                   UNSIGNED IN PREPARATION FOR
             *                   DIVISION.
6314 DF 15   INV1    STX     IX16
6316 DE 0B           LDX     TDIX
```

```
6318 A6 00              LDA A  0,X
631A 8B 80              ADD A  #$80
631C 08                 INX
631D DF 0B              STX    IDTX
631F 97 23              STA A  XKDVSR
6321 CE FFFF            LDX    #$FFFF
6324 DF 24              STX    XKDVND
6326 BD 62B9            JSR    XKDIVD
6329 DE 15              LDX    IX16
632B 96 26              LDA A  XKQUOT
632D A7 00              STA A  0,X
632F 08                 INX
6330 96 27              LDA A  XKQUOT+1
6332 A7 00              STA A  0,X
6334 08                 INX
RT1              MOTOROLA M68SAM CROSS-ASSMBLER

6335 8C 6000            CPX    #FIN
6338 2D DA              BLT    INV1
                 *
                 *             LOOK FOR BIGGEST RESULT.
633A CE 5000            LDX    #SCR16
633D DF 15              STX    IX16
633F EE 00              LDX    0,X       1ST VALUE INTO BIGGST.
6341 DF 2B              STX    BIGGST
                 *
                 *             TEST OTHER VALUES.
6343 DE 15       INV2   LDX    IX16
6345 8C 6000            CPX    #FIN
6348 2E 0E              BGT    INV3
634A 08                 INX
634B 08                 INX
634C DF 15              STX    IX16
634E FF 00              LDX    0,X
```

```
6350 9C 2B              CPX    BIGGST
6352 2D FF              BLT    INV2
6354 DF 2B              STX    BIGGST
6356 20 FB              BRA    INV2
                  *
                  *               DETERMINE SHIFT COUNT (SCNT) FROM
                  *               M.S. BIT SET IN BIGGST.
6358 C6 FF        INV3  LDA B  =$FF
635A 0C                 CLC
635B 96 2B              LDA A  BIGGST
635D 5C           INV4  INC B
635E 48                 ASL A
635F 24 FC              BCC    INV4
6361 D7 08              STA B  SCNT
                  *
6363 CE 5000            LDX    =SCRID
                  *
                  *               SHIFT ALL RESULTS LEFT.
6366 D6 08        INV5  LDA B  SCNT
6368 27 07        INV6  BEQ    INV7
RT1            MOTOROLA M68SAM CROSS-ASSMBLER

636A 68 01              ASL    1,X
636C 69 00              ROL    0,X
636E 5A                 DEC B
636F 20 F7              BRA    INV6
                  *
6371 08           INV7  INX
6372 08                 INX
6373 8C 6000            CPX    =FIN
6376 2D FE              BLT    INV5
                  *
                  *               ADDING =$80 PREPARES DATA
                  *               FOR OUTPUT.
```

```
6378 CE 4800          LDX     =SSBLK
637B BD 61BF          JSR     *CV16B
637E C6 80            LDA B   =$80
6380 CE 4800          LDX     =SSBLK
6383 A6 00      INVB  LDA A   0,X
6385 1B               ABA
6386 A7 00            STA A   0,X
6388 08               INX
6389 8C 5000          CPX     =$5000
638C 2D F5            BLT     INVB
638E 39               RTS
                *
                *
                *
                *
                *****************************************************************
                **
                *       SUBROUTINE TO CHANGE RESULTS OF VELOCITY
                *       INTEGRATION SO THAT BOTH POS. AND NEG NUMBERS
                *       ARE OUTPUT. THIS ALLOWS BETTER HORIZONTAL RES-
                *       OLUTION WHEN DEPTH IS USED AS X-AXIS. EACH BYTE
                *       IS SHIFTED LEFT. AND ALL MS BYTES ARE SEARCHED
                *       FOR THE LARGEST POS. VALUE.  THIS VALUE IN THE
                *       B REG. IS SUBTRACTED FROM ALL OTHERS AND $7F IS
                *       ADDED TO ALL.
```



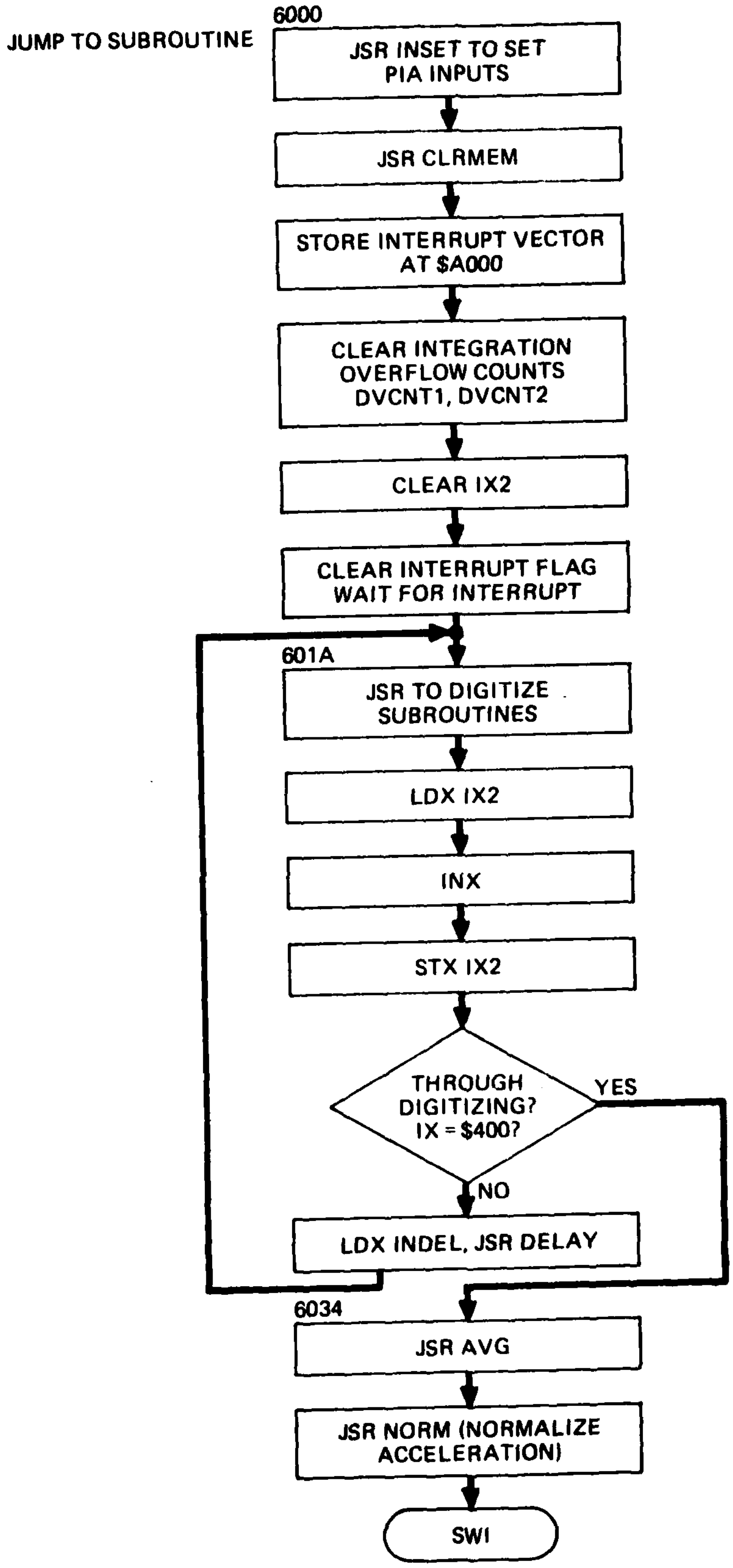
```
638F 5F         FUDGE CLR B
6390 CE 5000          LDX     =SCR15
6393 68 01      FUD1  ASL     1,X
6395 69 00            ROL     0,X
6397 E1 00            CMP B   0,X
```

```
6399 2A 02                BPL     FUD2
639B F6 00                LDA B   0,X
639D 08           FUD2    INX
639E 08                   INX
639F 8C 6000              CPX     #FIN      FOUND BIGGEST YET?
63A2 2D EF                BLT     FUD1
63A4 CE 5000              LDX     #SCR16
63A7 A6 00        FUD3    LDA A   0,X
63A9 10                   SBA
63AA 8B 7F                ADD A   #$7F      ADD OFFSET.
63AC A7 00                STA A   0,X
63AE 08                   INX
63AF 08                   INX
63B0 8C 6000              CPX     #FIN
63B3 2D F2                BLT     FUD3
63B5 39                   RTS
                  *
                  *
                  *
                  ***********************************************
                          END
```

SYMBOL TABLE

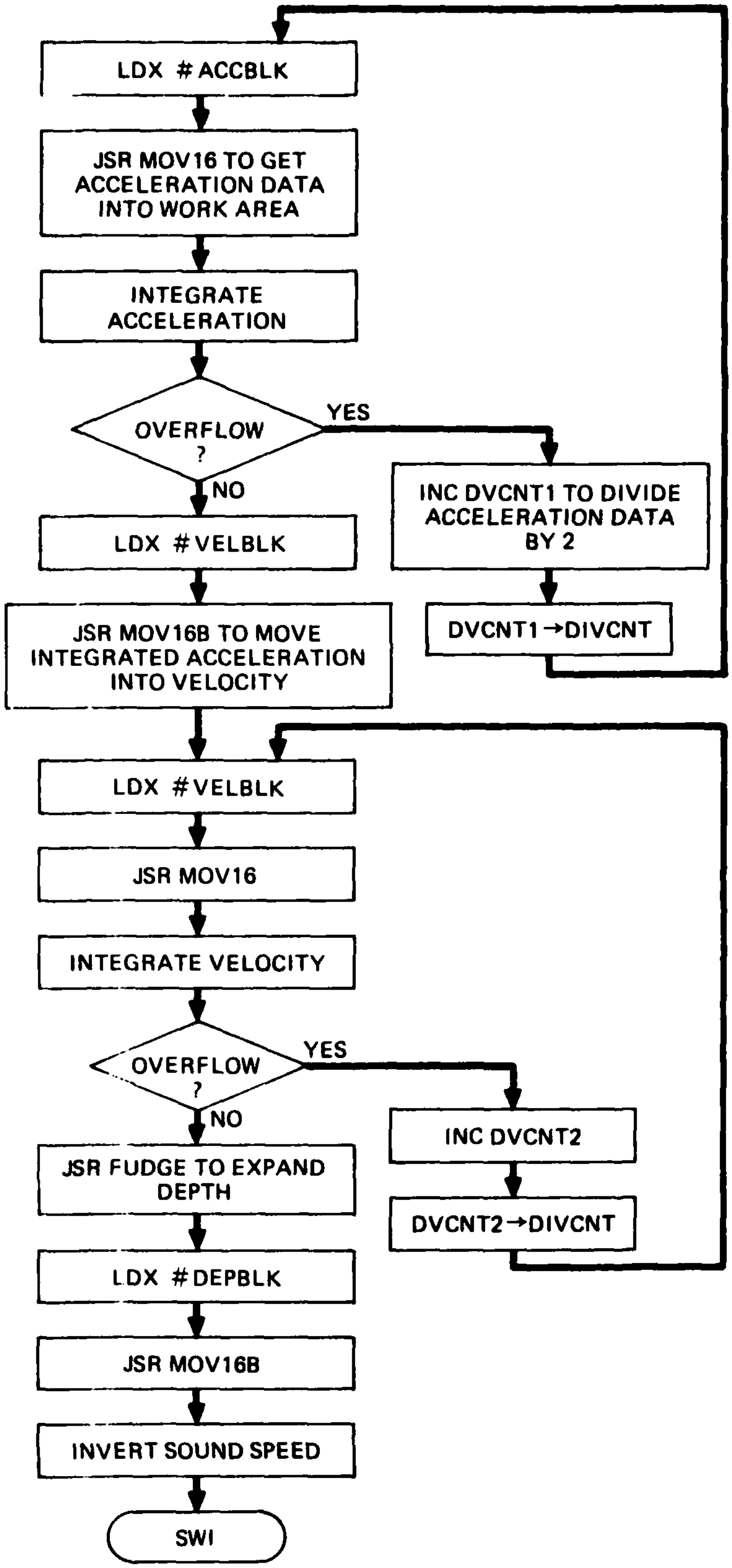
OFLAY	E0E0	ACCBLK	2000	TOBLK	2800	AMPBLK	3000	VFLBLK	3800
DEPBLK	4000	SSBLK	4800	SCR16	5000	TIME	0000	FIN	6J00
XSEL	0000	YSEL	0001	INDEL	0002	OUTDEL	0004	DVCNT1	0006
DVCNT2	0007	DIVCNT	0008	SCNT	0008	ACCIX	0009	TOIX	000B
AMPIX	000D	VFLIX	000F	DEPIX	0011	SSIX	0013	IX16	0015
IX2	0017	AVGMSB	0019	AVGLSB	001A	XTOUT	001B	XSCRCH	001C
YSCRCH	001E	IX3	0020	NEGFLG	0022	XKDVSR	0023	XKDVND	0024
YKQUOT	0026	XKDSPL	0028	INITX	0029	INITY	002A	BIGGST	002B
PRA	8004	DDRA	8004	CRA	8005	PRB	8006	DDRB	8006
CRB	8007	INTVEC	601A	A2DEND	6034	MAIN1	603E	MAIN2	6053
MAIN3	6059	MAIN4	606E	MAIN5	6071	MAIN6	6077	OUTDTA	6092
NSET	60AB	CLRMEM	60E4	ZLOOP	60EB	A2D1	60F1	A2D2	6106
2D3	611B	AVG	6130	AVGLP1	613B	DECNTR	6147	AVGLP2	614C
ORM	6158	NORM1	615B	MOV16	6167	M1	616E	M2	6179
3	6170	M4	6184	M5	6185	INIGHT	6199	I1	61A3
2	61B3	I3	61BE	MOV16M	61BF	MR1	61C6	OUTSET	61DB
JTX	61F8	OUT1	6205	OUT1X	620A	OUTY	6220	OUTY2	6233
JTY3	623E	OUT1Y	6243	OUT1XU	6259	PENUP	6269	OUT1YU	626F
NSTRT	6285	P1	628D	P2	6291	SELBLK	62A0	S1	62A3
JTBL	62AB	XKDIVD	62B9	DVDLPJ	62C1	DVDLP1	62D2	DVDLP2	62D6
VNSUB	62E3	DVSHFT	62FA	DVDERR	62FA	DVDEND	62FF	DVDLP3	6309
NVERT	630C	INV1	6314	INV2	6343	INV3	6358	INV4	6350
NV5	6366	INV6	6368	INV7	6371	INV8	6383	FUDGE	638F
JD1	6393	FUD2	639D	FUD3	63A7				

.00.18.UCLP. AA31. 1.008KLNS.



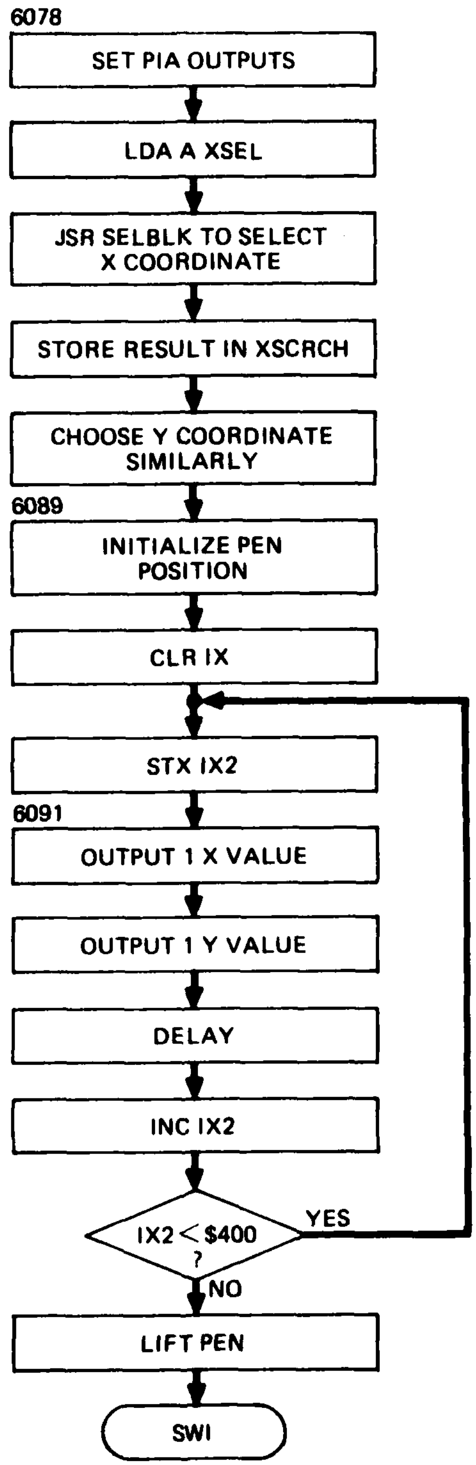
ARL:UT
AS-81-855
RTT - GA
8 - 3 - 81

MAIN PROGRAM



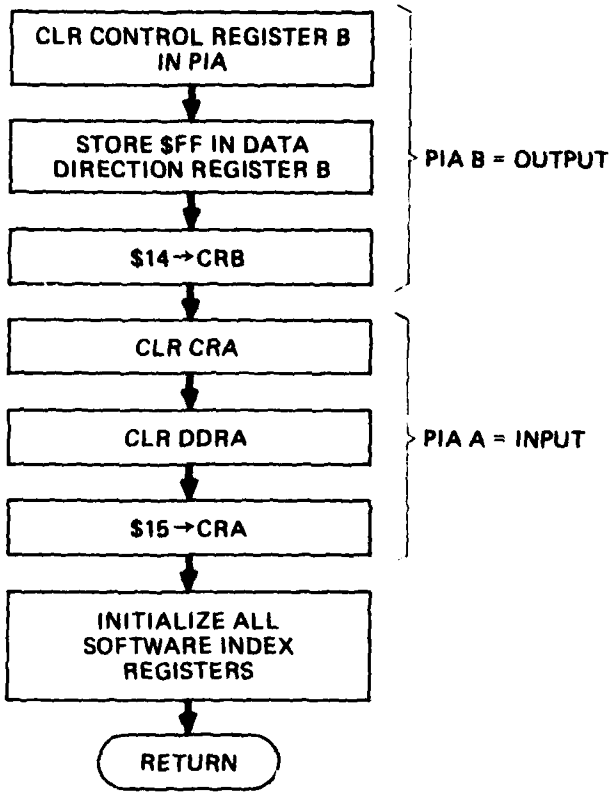
ARL:UT
AS-81-856
RTT - GA
8 - 3 - 81

MAIN PROGRAM (Cont'd)



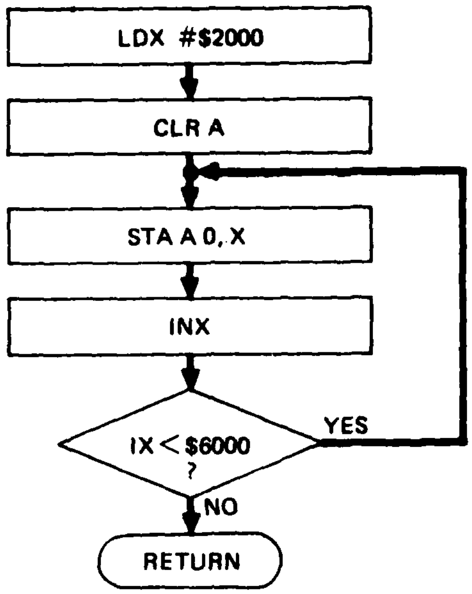
ARL:UT
AS-81-857
RTT - GA
8 - 3 - 81

MAIN PROGRAM (Cont'd)



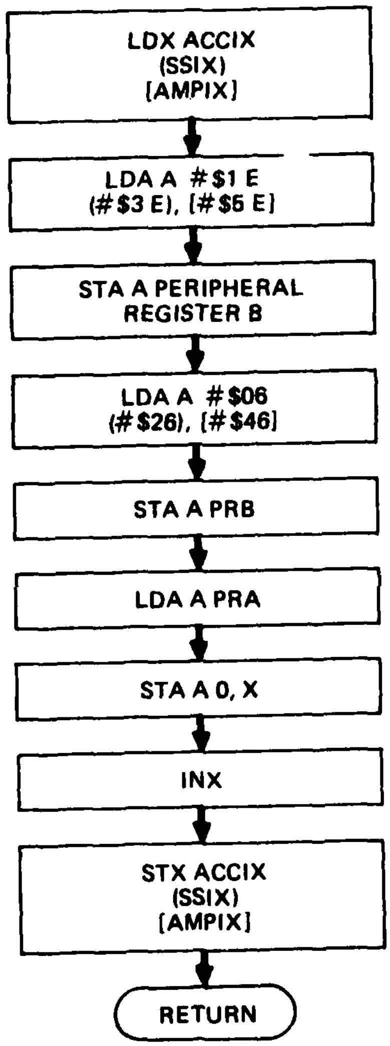
SUBROUTINE INSET

ARL:UT
AS-81-858
RTT - GA
8 - 3 - 81



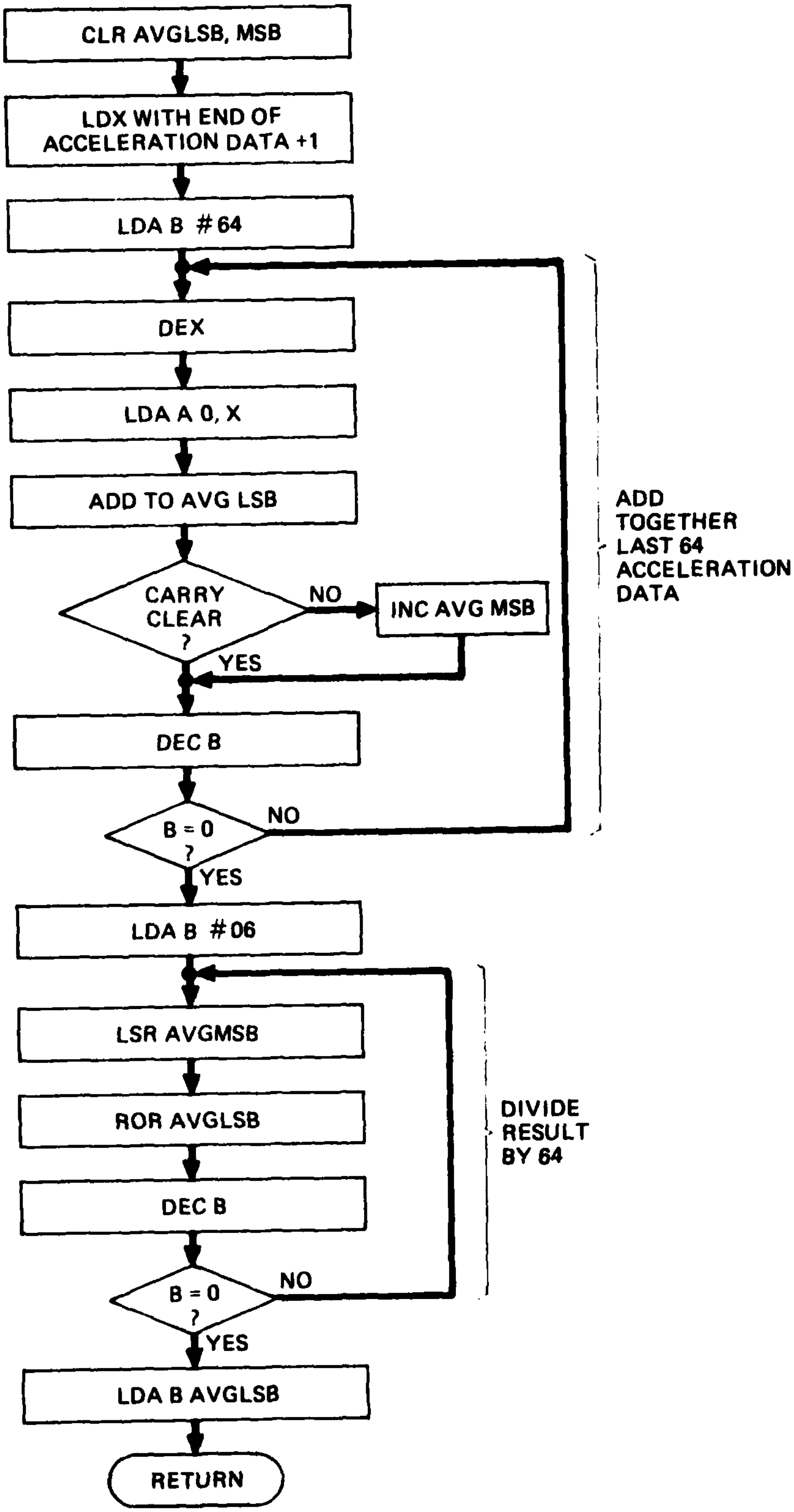
SUBROUTINE CLRMEM

ARL:UT
AS-81-859
RTT - GA
8 - 3 - 81



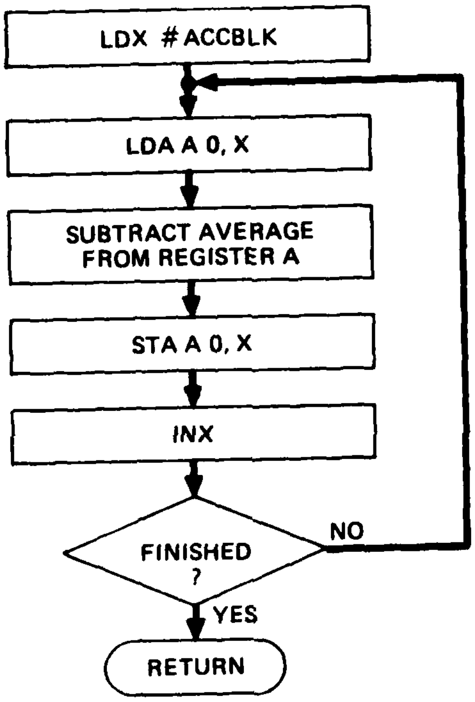
**SUBROUTINES A2D1,
(A2D2), [A2D3]**

ARL:UT
AS-81-860
RTT - GA
8 - 3 - 81



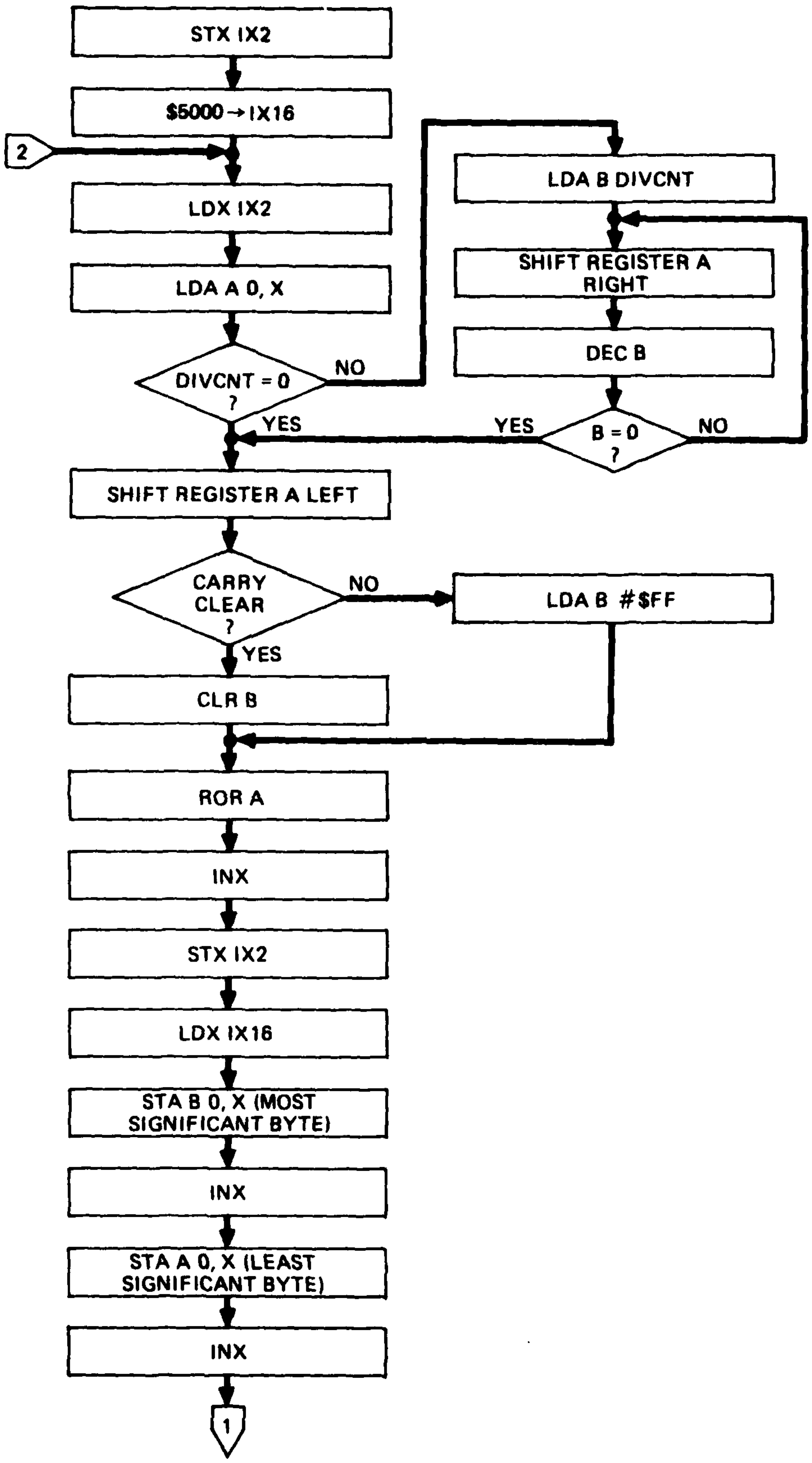
ARL:UT
AS-81-861
RTT - GA
8 - 3 - 81

SUBROUTINE AVG



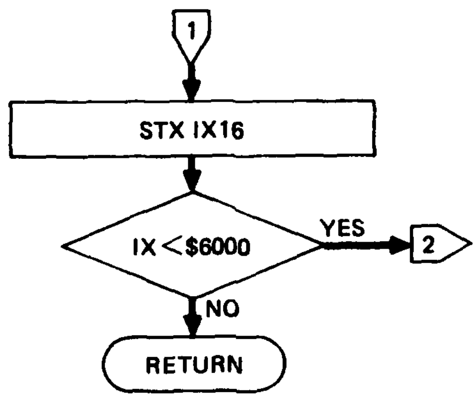
SUBROUTINE NORM

ARL:UT
AS-81-862
RTT - GA
8 - 3 - 81



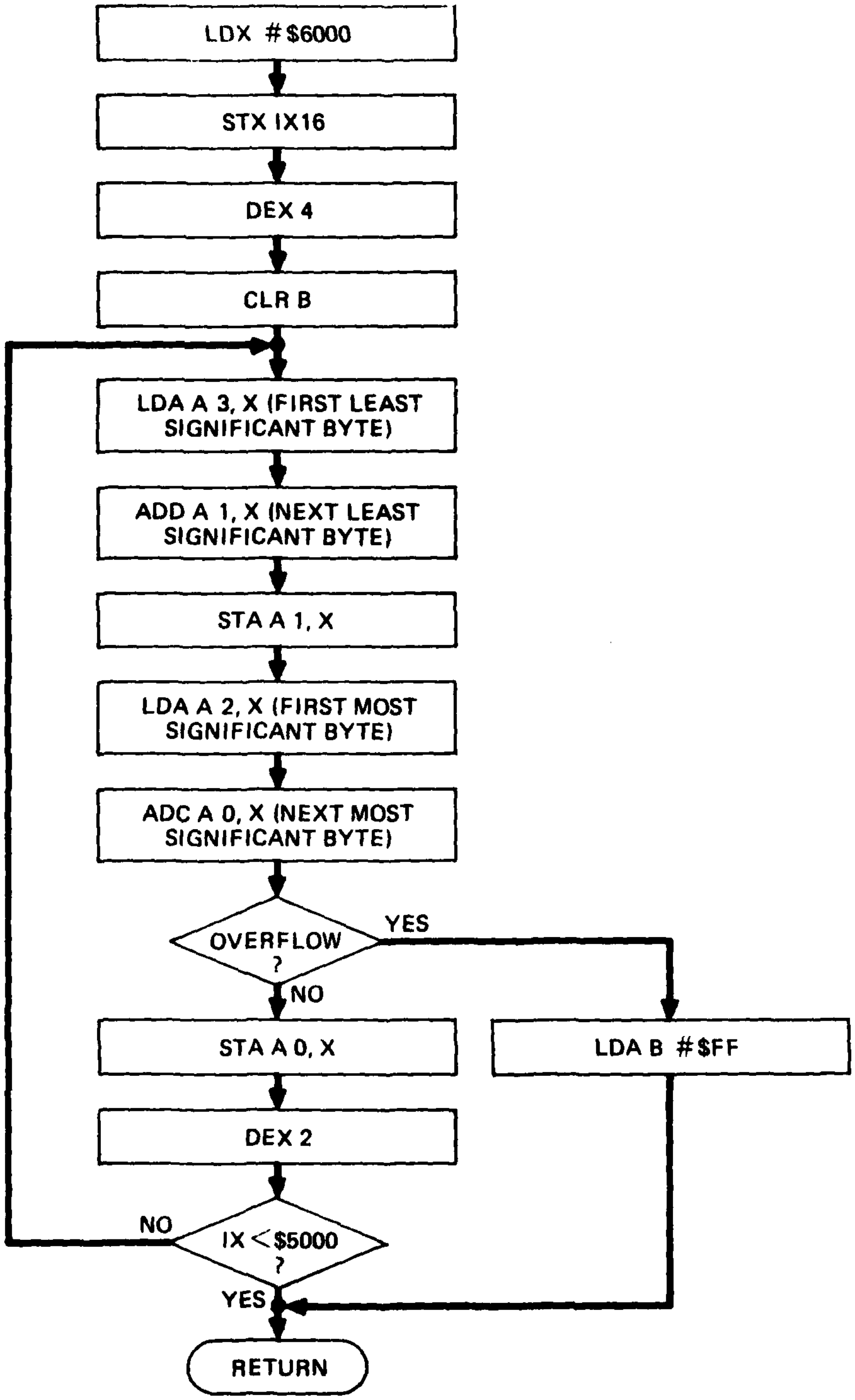
SUBROUTINE MOV16

ARL:UT
AS-81-863
RTT - GA
8 - 3 - 81



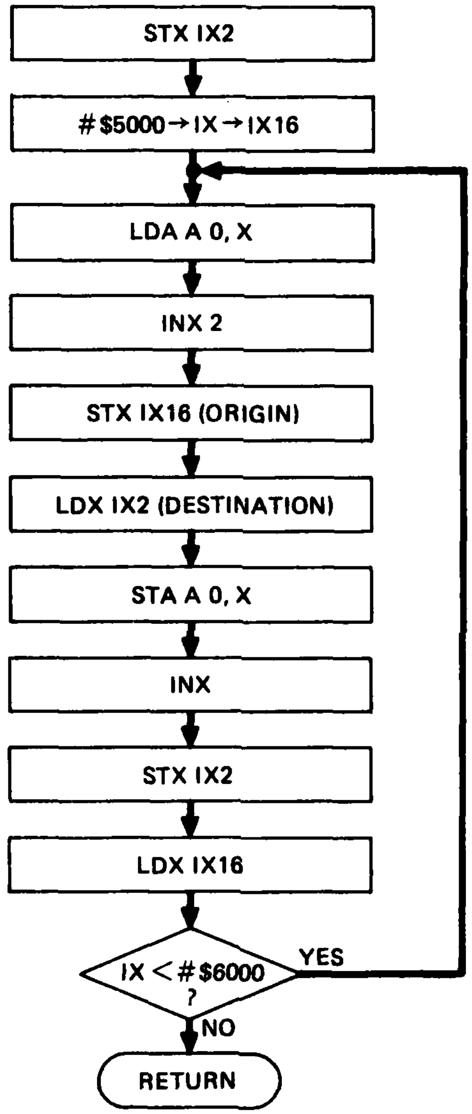
SUBROUTINE MOV16 (Cont'd)

ARL:UT
AS-81-864
RTT - GA
8 - 3 - 81



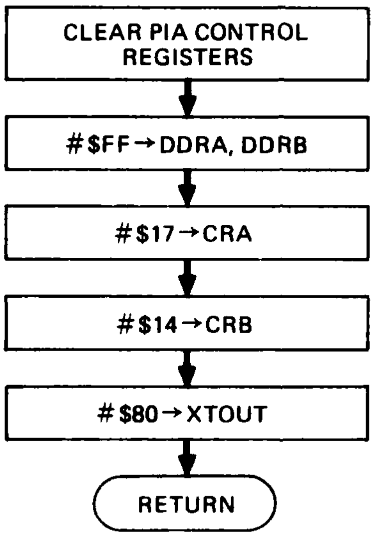
SUBROUTINE INTGRT

ARL:UT
AS-81-865
RTT - GA
8 - 3 - 81



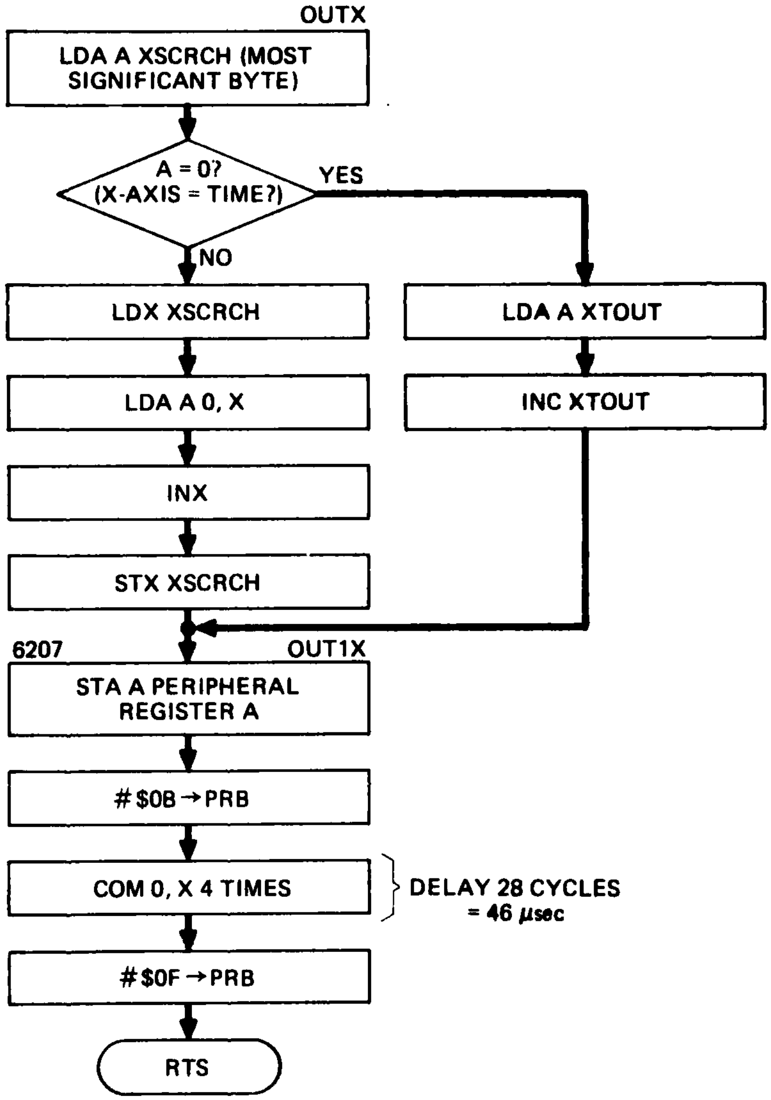
SUBROUTINE MOV16 B

ARL:UT
AS-81-866
RTT - GA
8 - 3 - 81



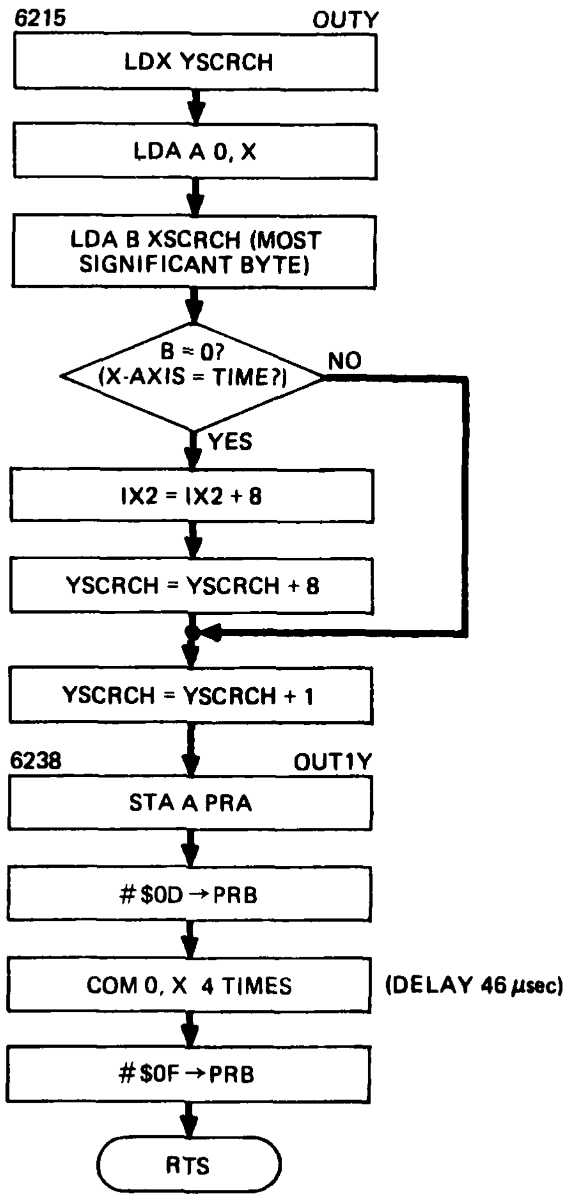
SUBROUTINE OUTSET

ARL:UT
AS-81-867
RTT - GA
8 - 3 - 81



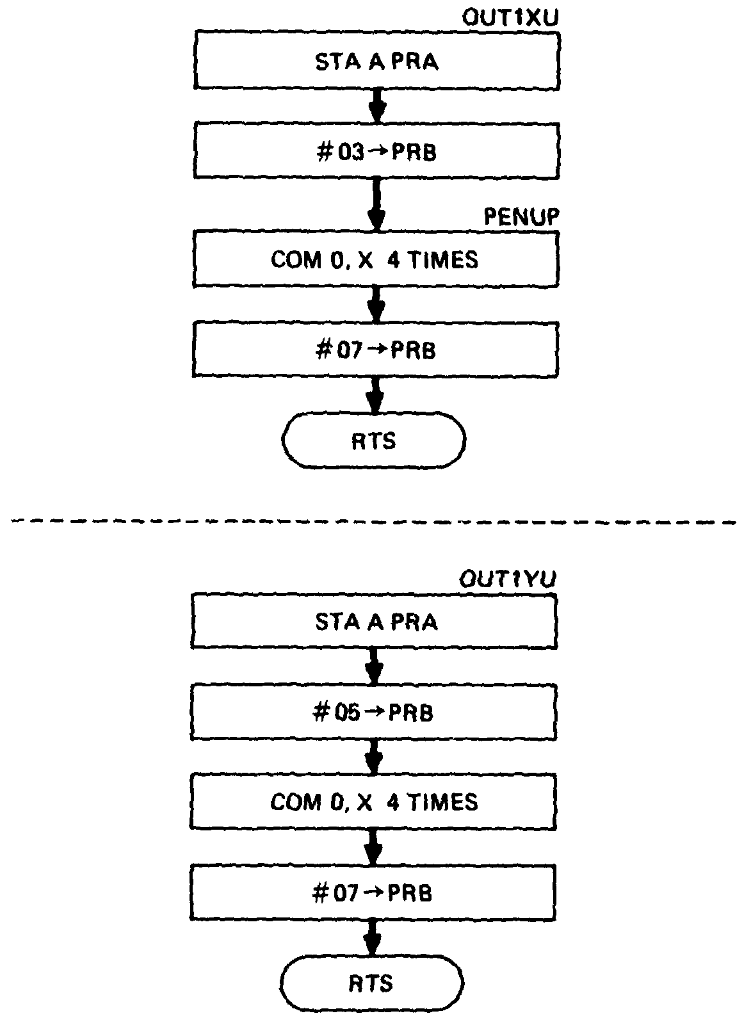
SUBROUTINES OUTX, OUT1X

ARL:UT
AS-81-868
RTT - GA
8 - 3 - 81



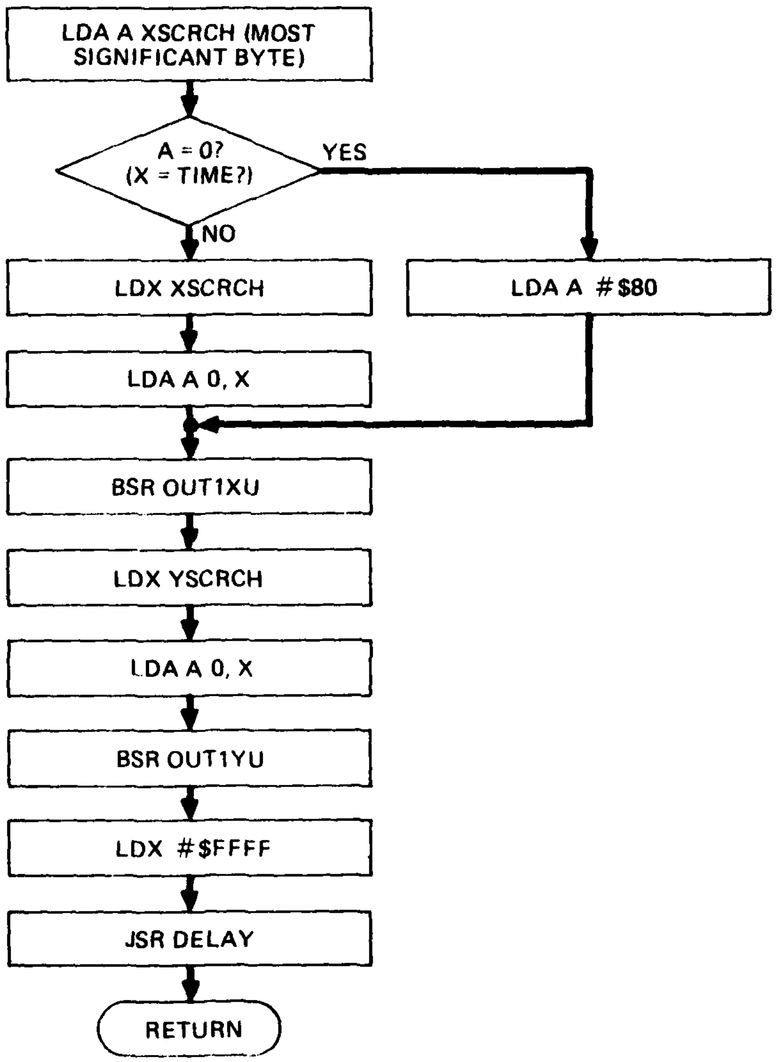
SUBROUTINES OUTY, OUT1Y

ARL:UT
AS-81-869
RTT - GA
8 - 3 - 81



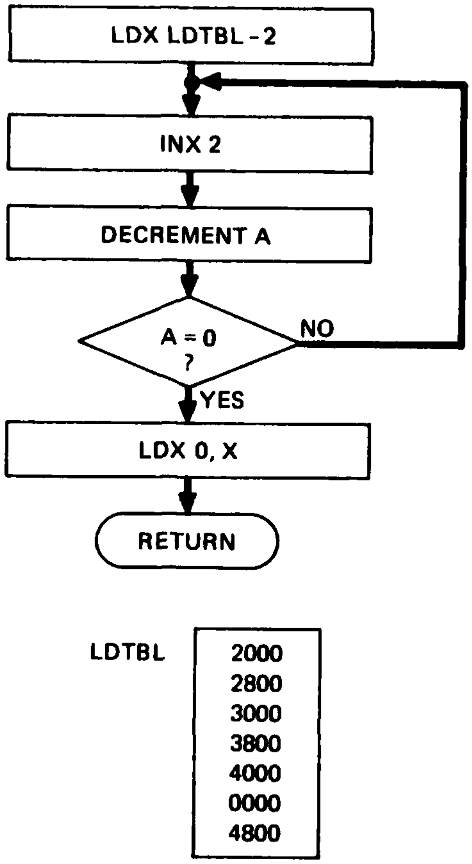
SUBROUTINES OUT1XU, PENUP, OUT1YU

ARL:UT
AS-81-870
RTT - GA
8 - 3 - 81



SUBROUTINE PNSTRT

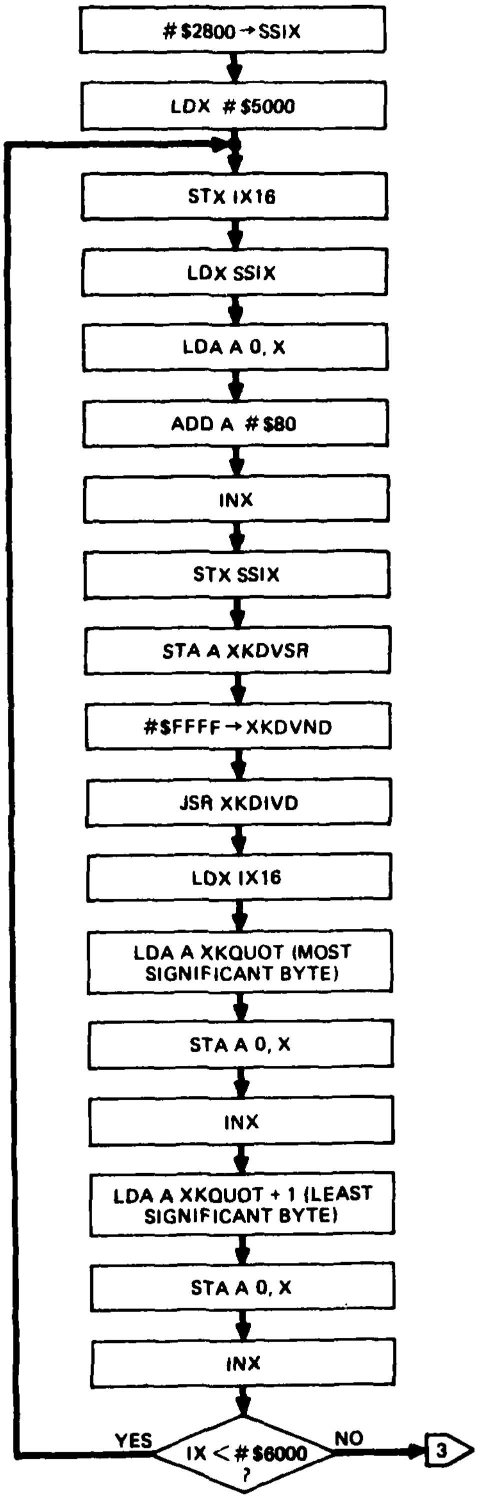
ARL:UT
AS-81-871
RTT - GA
8 - 3 - 81



FOR XKDIVD FLOWCHARTS, SEE MOTOROLA APPLICATIONS MANUAL

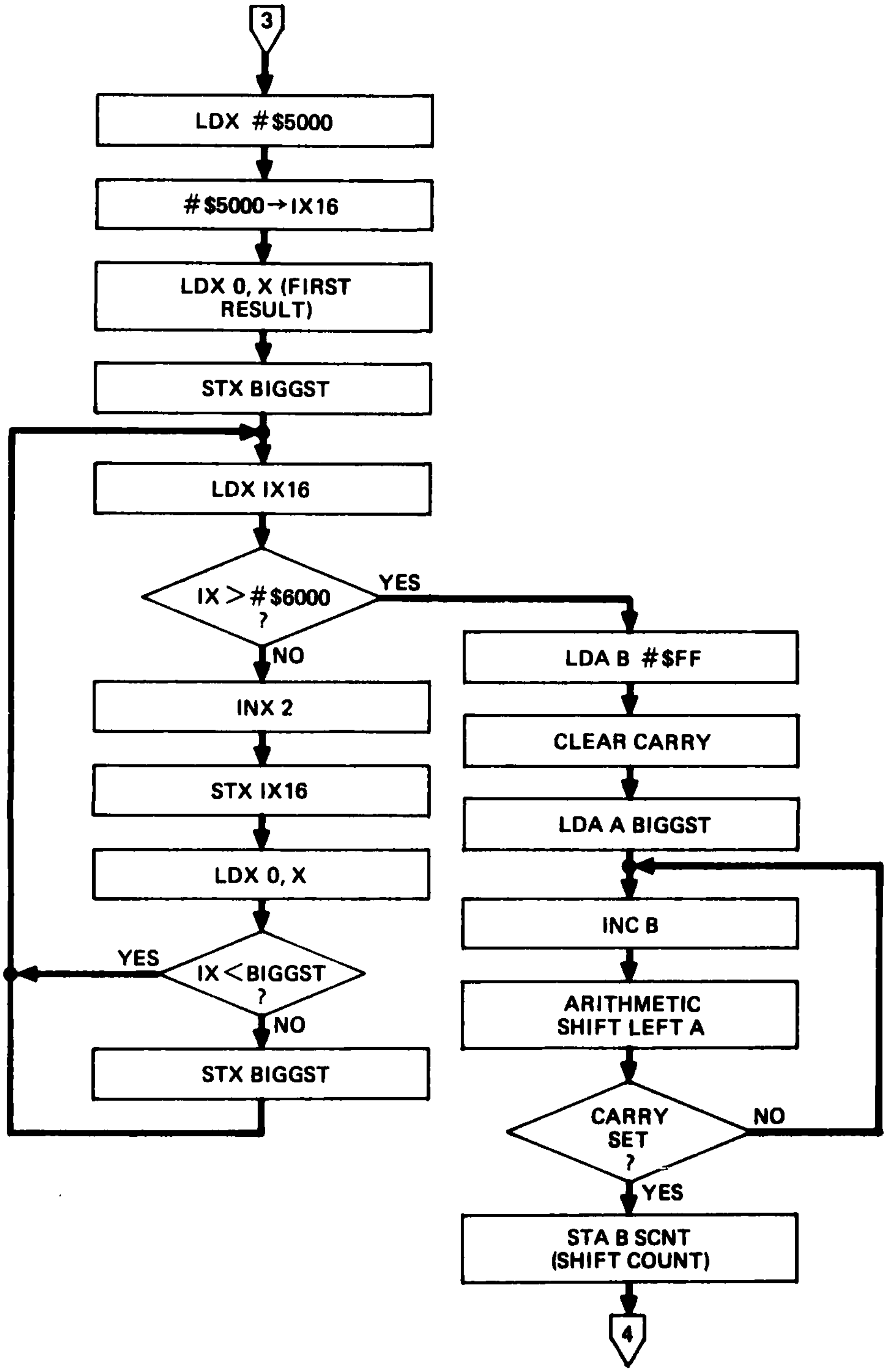
SUBROUTINE SELBLK

ARL:UT
AS-81-87
RTT - G
8 - 3 - 81



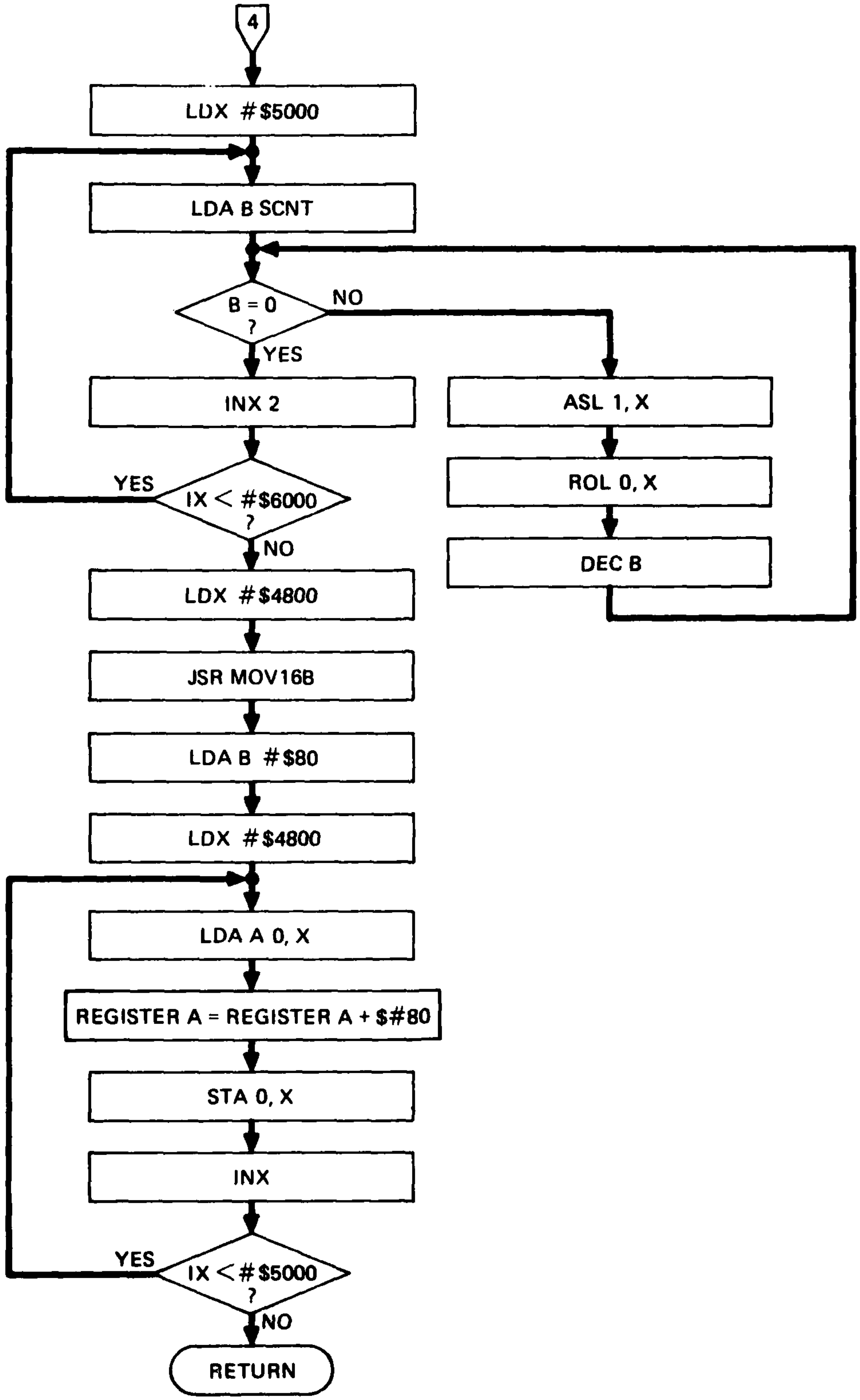
ARL:UT
AS-81-873
RTT - GA
8 - 3 - 81

SUBROUTINE INVERT



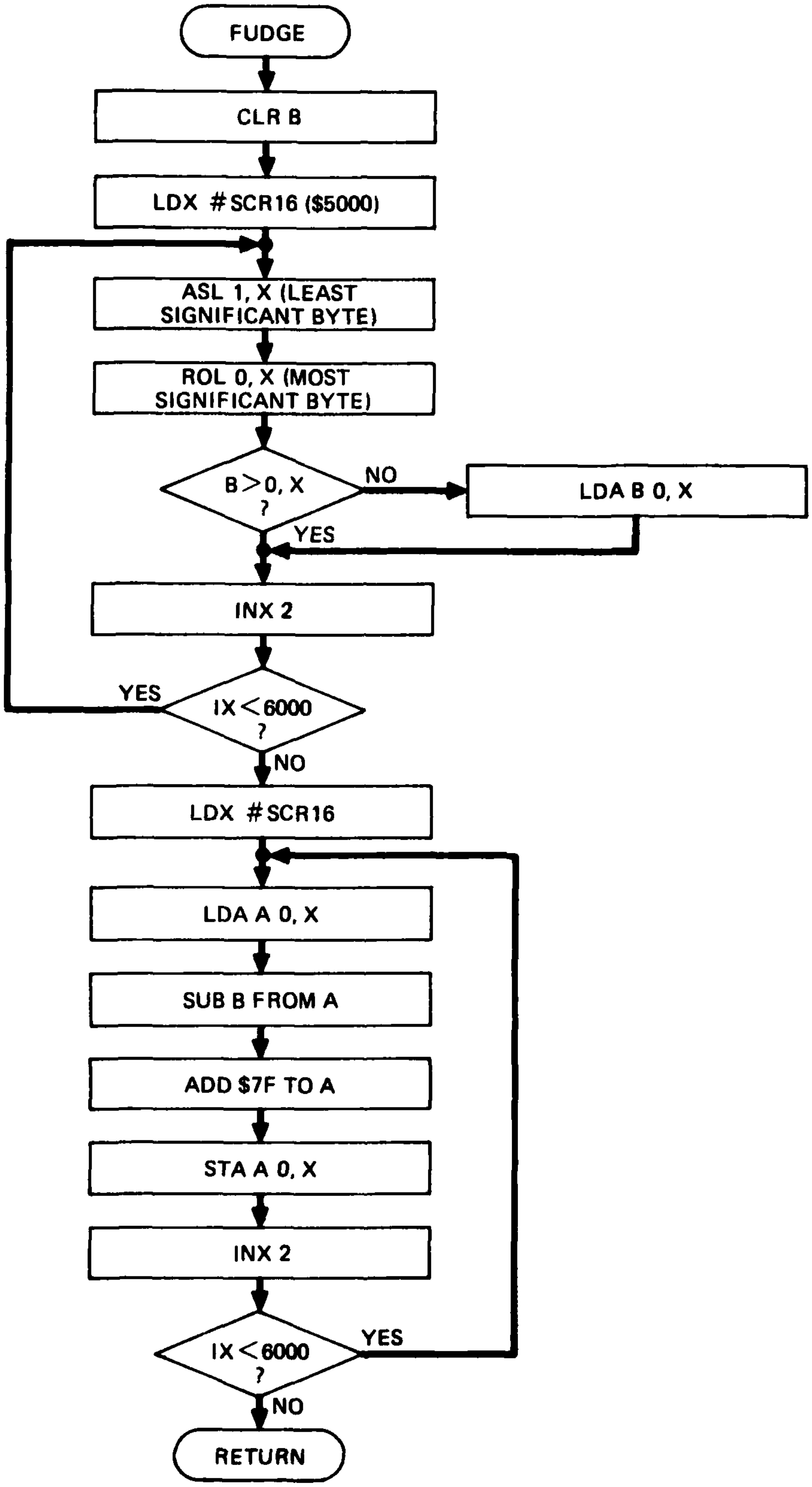
SUBROUTINE INVERT (Cont'd)

ARL:UT
AS-81-874
RTT - GA
8 - 3 - 81



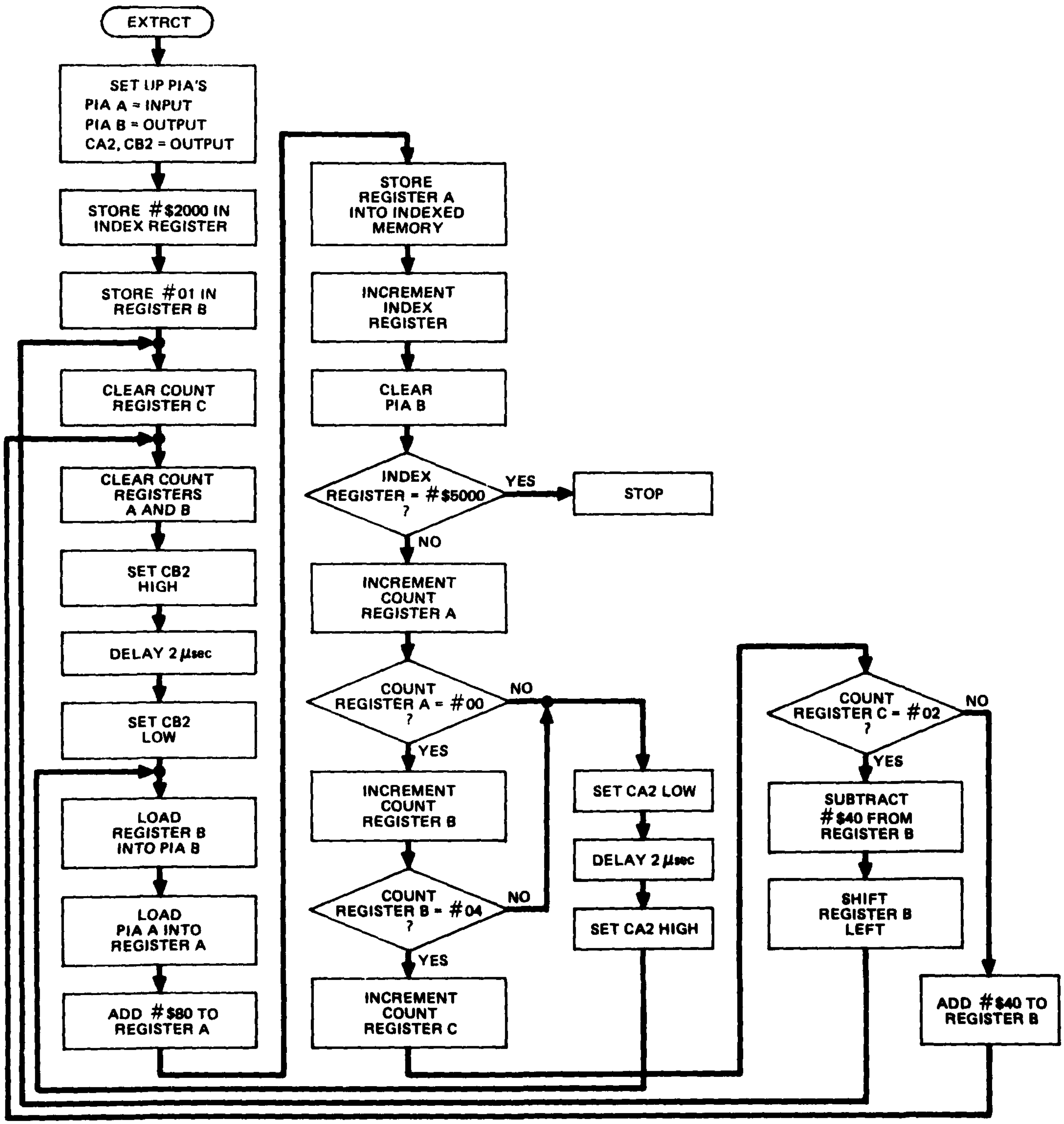
ARL:UT
AS-81-875
RTT - GA
8 - 3 - 81

SUBROUTINE INVERT (Cont'd)



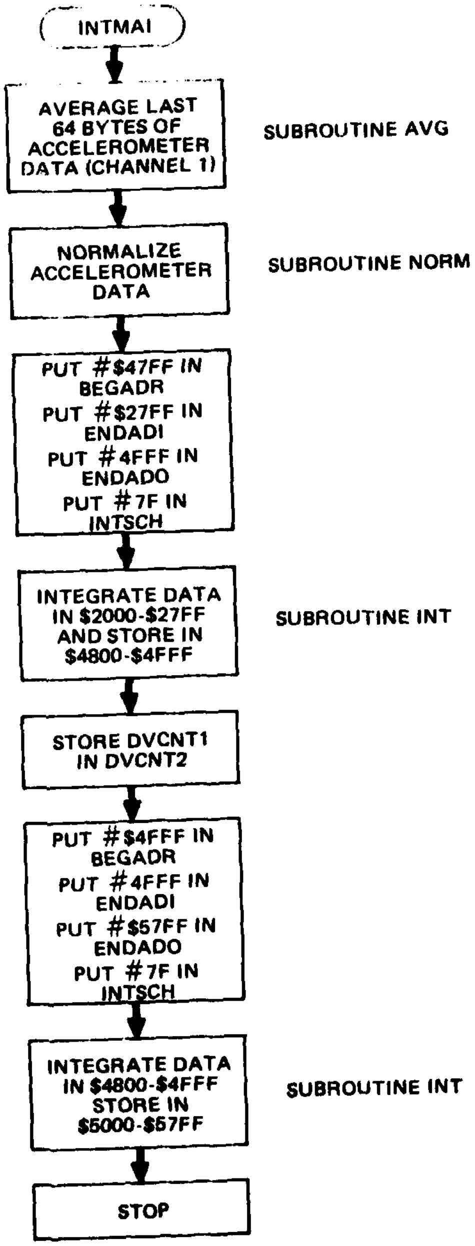
ARL:UT
AS-81-876
RTT - GA
8 - 3 - 81

SUBROUTINE FUDGE



ROUTINE EXTRCT

ARL:UT
AS-81-677
RTT - GA
8 - 3 - 81



$0006 DVCNT
$0007 DVCNT1
$0008 DVCNT2
$0009 INTSCH
$000A, 000B BEGADR
$000C, 000D ENDADO
$000E, 000F ENDADO
$0010, 0011 IXSCH1
$0012, 0013 IXSCH2

BEGADR + 1 = BEGINNING ADDRESS OF OUTPUT BLOCK

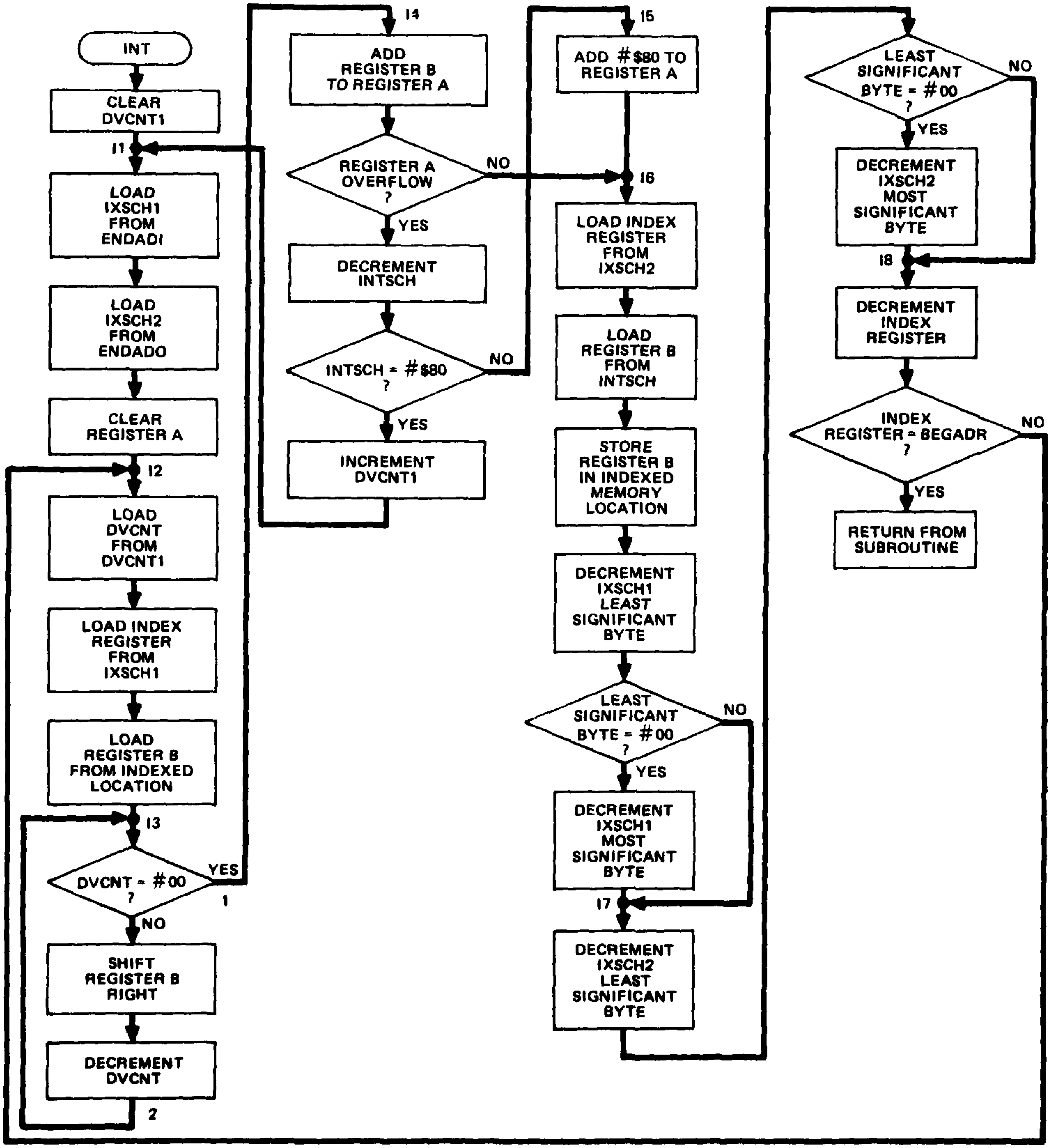
ENDADI = ENDING ADDRESS OF INPUT BLOCK

ENDADO = ENDING ADDRESS OF OUTPUT BLOCK

INTSCH = TEMPORARY STORAGE FOR INTEGRATED DATA BYTE

ROUTINE INTMAI

ARL:UT
AS-81-878
RTT - GA
8 - 3 - 81



SUBROUTINE INT

ARL:UT
AS-81-879
RTT - GA
8 - 3 - 81

APPENDIX D

ONR CODE 480 PROGRAM

DOCUMENTATION

S. R. Addy, E. W. Behrens, T. R. Haines, D. J. Shirley and J. L. Worzel, "Correlation of Some Lithologic and Physical Characteristics of Sediments with High Frequency Subbottom Reflection Types," Proceedings of the 11th Annual Offshore Technology Conference, Houston, Texas, 30 April - 3 May 1979.

A. L. Anderson, "Acoustics of Gas-Bearing Sediments," Applied Research Laboratories Technical Report No. 74-19 (ARL-TR-74-19), Applied Research Laboratories, The University of Texas at Austin, May 1974.

A. L. Anderson and L. D. Hampton, "In Situ Measurement of Sediment Acoustic Properties During Coring," presented at the ONR Symposium on Physical and Engineering Properties of Deep-Sea Sediments, Airlie House, Airlie, Virginia, 24-27 April 1973.

A. L. Anderson and L. D. Hampton, "Measurement of In Situ Acoustic Properties During Sediment Coring," presented at the ONR Symposium on the Physics of Sound in Marine Sediments, Lakeway Inn, Austin, Texas, 8-10 May 1973.

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L. D. Hampton, "ARL Experience with Acoustics and Gas in Sediments," presented at Symposium on Natural Gases in Marine Sediments and Their Mode of Distribution, The University of California Lake Arrowhead Conference Center, Lake Arrowhead, California, 28-30 November 1972.

L. D. Hampton and A. L. Anderson, "Acoustics and Gas in Sediments: Applied Research Laboratories (ARL) Experience," in Natural Gases in Marine Sediments, Marine Science Vol. III, edited by Isaac R. Kaplan (Plenum Press, New York, 1974).

J. M. Hovem, "Some Aspects of Sound Propagation in Saturated Sand," presented at the Seminar on Bottom Effects in Underwater Sound Propagation, Miami, Florida, 26-28 April 1979.

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